TFW-SH8-91-001

WATERSHED AND STREAM CHANNEL CUMULATIVE EFFECTS ANALYSIS USING AERIAL PHOTOGRAPHY AND GROUND SURVEY DATA

INTERIM REPORT

By

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&WILDLIFE

1991

MEMORANDUM

TO: Nancy Sturnham, DNR

Tim Beechie, AMSC Project Liaison

Kate Sullivan, SHAM Project Liaison

FR: Dave Somers

Jeanette Smith

Robert Wissmar

DT: July 3, 1991

RE: Interim Report on the "Watershed and Stream Channel Cumulative Effects Analysis Using Aerial Photography and Ground Survey Data" (Watershed Analysis) TFW project.

As you are aware, the Watershed Analysis study which we are conducting will require additional time for completion. We are submitting this interim report on the project for your review and comment. The report is intended to:

1. Describe the status of the project and projected timeline for completion;
2. Present our conceptual approach to watershed analysis in the context of cumulative effects;

3. Describe the past use of remote sensing for stream, riparian, and watershed studies and some critical issues which must be addressed in any watershed or stream analysis system;

4. Describe our study methods;

5. Present a preliminary analysis of changes in stream habitat in Taneum creek as determined from physical stream surveys conducted for this project and historical stream survey data.

Since the aerial photograph analysis is not completed, we do not believe that a preliminary discussion of results is appropriate. However, since the issue of watershed screening and analysis is currently receiving great attention, we think that a discussion of our conceptual approach to defining cumulative effects and watershed analysis is · important. Further, the task of determining methods for watershed screening and analysis requires a careful assessment of all physical and biological features of watersheds and the processes influencing them. While this topic has been discussed at great length within the TFW steering committees, we hope that presentation of a watershed model will stimulate thought on the major biological and physical components and processes within watersheds. This model can serve as a checklist for comparison against proposed watershed screening and analysis tools.

We would like to request that the project timeline be adjusted to allow six additional months for completion beyond the original anticipated completion date of June 30, 1991. We recognize that this is a considerable extension, however we feel it is a realistic timeframe for completion. Several factors have contributed to the need for this adjustment;

A delay in receiving our photographs from the photo supply company caused a slip in schedule of approximately 3 months;

The amount of time required to perform relative and absolute control of the photographs for use in the analytical stereoplotter was underestimated in the original proposal. Photo control was begun using USGS data, however it was determined that use of DNR photo control data was desirable in order to allow integration with GIS layers developed in this project with existing DNR GIS layers. This required acquisition of an additional set of aerial photographs and an associated delay;

Scheduling conflicts have slowed the rate of photo analysis from that anticipated in the original schedule.

We anticipate that the following checkpoints for completing subtasks is reasonble to achieve:

Sept. 15 - Completion of photo control and digitization of all GIS layers.

October 31 - Completion of analysis.

November 15 - Draft Final Report Submitted to TFW.

December 15 - Comments due on Draft Final Report.

December 31 - Final Report submitted to TFW.

We are very anxious to complete this project and present our results and experiences for use within TFW. We have had fairly extensive contact with other forest resource management agencies, particularly the U.S. Forest Service, and we have found great support for the approach taken in this study. It is our hope that the TFW process, and the design of watershed screening and analysis, will benefit from this effort.

Project Status

The following work has been completed for the project;

* Stream surveys completed in selected segments of Hoh tributaries, Mashel River, and Taneum Creek.

* Acquisition of aerial photographs as described in Table of the interim report.

* Acquisition of photo control data from DNR photogrammety department.

* Digitization or acquisition of the following GIS layers;

Area	Layer	Completed
Hoh River	- geology	x
	- hydrography	x
	- soils	x
	- roads	x
	- vegetation	
	- riparian opening	
	- landslides	
Mashel River	- geology	x
	- soils	x
	- roads	x
	- veil cover	x
	- landslides	x
	- hydrography	x
	- riparian opening	
Taneum Creek	- geology	x
	- soils	**x**
	- hydrography	x
	- roads	
	- vegetation	
	- landslides	
	- riparian opening	

* Manual RAPID analysis of Hoh tributaries and Mashel River;
* Comparison of historic and recent stream survey data for Taneum Creek.

Work to be done for project;

* Finish relative and absolute orientation for aerial photos.
* Digitization of layers not completed for each watershed.
* GIS analysis
* Comparison of manual and stereoplotter measurements with ground data.
* Report results, interpretation, and recommendations.

Please feel free to make any comments about this interim report and proposed schedule. We would be happy to discuss this further with you or other committee members if it would be helpful.

INTERIM REPORT

WATERSHED AND STREAM CHANNEL CUMULATIVE EFFECTS ANALYSIS USING AERIAL PHOTOGRAPHY AND GROUND SURVEY DATA

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JULY 3, 1991

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INTRODUCTION

This document is intended to serve as an interim report on the "Watershed and Stream Channel Cumulative Effects Analysis Using Aerial Photography and Ground Survey Data" project. This study is funded by the Washington Department of Natural Resources in cooperation with the Sediment, Hydrology, and Mass Wasting Committee (SHAM), and the Ambient Monitoring Steering Committee (AMSC) of the Timber/Fish/Wildlife (TFW) process. This report provides a description of approach taken in the study, particularly for watershed cumulative effects analysis, and presents information and experience gained through the project to date.

We have tried to prepare the report to provide information relevant to the current activities of TFW and the Washington Forest Practice Board, specifically the design and implementation of watershed screening, watershed analysis, and stream condition thresholds. At the time this project was originally funded, these issues were not a part of any formal regulatory process, although similar issues had been discussed at length within TFW. Recent legal and political events have moved watershed level analysis towards adoption within existing regulatory processes. It is our hope that our project experiences will assist in the development of watershed analysis which is technically well grounded, efficient, and effective in providing resource managers with appropriate and interpretable information regarding watershed conditions. The scope of this study is limited to factors influencing the abundance and quality of anadromous and resident fisheries habitat.

Goals and Objectives of Project

The goals of this project are:

Test feasibility and utility of aerial photograph interpretation for quantifying watershed and stream conditions, and upland disturbance indicators;

Evaluate the influences of land use and watershed condition on riparian canopy and stream channel conditions;

Establish recommendations to TFW for quantifying watershed, riparian, and stream conditions using aerial photography.

The objectives of this project are:

Develop a concurrent ground/aerial data set for three watersheds;

2. Establish the relationship between ground and aerial data;

3. Develop standardized methodology for aerial analysis of watersheds, riparian zones, and stream channels which complement ground survey data;

Test hypothesis that riparian canopy opening is an indicator of changes in watershed hydrology, sedimentation, and riparian vegetation disturbance; that riparian canopy response will vary by segment type; and that riparian canopy opening and segment type are accurate indicators of instream habitat conditions.

In order to accomplish these goals and objectives, and assess the efficacy of remote sensing, we have identified several subtasks:

1) Adopt a definition of individual and cumulative effects;

2) Develop a watershed model which identifies the key physical and biological elements and processes within watersheds being managed, at least in part, for forest resource production;

3) Identify spatial and temporal scales at which key elements and processes are manifest;

4) Identify methods used to measure or assess stream and watershed condition;

5) Determine capabilities of quantifying stream or watershed elements and processes from aerial photographs, or other remote sensing techniques;

6) Make recommendations for implementation of remote sensing applications for watershed analysis and for further research.

This interim report is formatted as closely as possible to the anticipated outline of the final report. Major topical sections are:

1. Framework for watershed and cumulative effects analysis;
2. Review of historical use of aerial photo analysis and remote sensing for identifying and quantifying aquatic and terrestrial features;

   Description of Project Methods;

4. Case Studies (incomplete);
5. Discussion of Results (incomplete);
6. Conclusions and Recommendations (incomplete).

COMPONENTS OF WATERSHED CUMULATIVE EFFECTS ANALYSIS

Overview

In order to develop and test a method for watershed analysis, we have adopted a watershed model which serves as a template for the development of the analysis. This model identifies the key components of the watershed, including physical and biological resources, and the processes working to define the condition of these resources.

The TFW research and monitoring program has emphasized the long term goal of developing management tools for assessing and predicting environmental and ecological dynamics from spatial scales encompassing physiographic ecoregions, watersheds, and habitat units (pools, fifties, etc.). The "Watershed Analysis" study was proposed and designed to be consistent with this goal and to provide a method by which information from these levels could be consistently collected and interpreted.

For the purposes of this study, the lowest level of analysis will be at the habitat unit level. Physical, chemical, and biological conditions at this level determine the utilization and suitability of the habitat for anadromous and resident salmonid fishes. Ideally, physical and biological conditions found at the habitat unit level can be linked quantitatively or qualitatively to channel,watershed, and regional processes and conditions (See Figure 1.).

We have adopted a working definition of "cumulative effects" in order to determine the scope of processes being considered in our watershed analysis.

Cumulative Effects

We have examined several definitions of cumulative effects (CE). Each of these definitions was compared to our current understanding of the interactions between watersheds, fish habitat, and land management.

Vlachos (1985) identifies four critical elements which should be recognized in CE analysis. These are:

1) The nature of inducing actions
2) The scale or extent of on-going transformations
3) The rate and timing of change
4) The arena of operations or the physical setting where the various actions take place

In other words we must identify the source of impacts, the magnitude of the impact, the rate of change caused by the impact, and the background features of the environment which will influence the impacts. Presumably, the background setting is primarily of interest because of it's influence on the identification and determination of the first three factors.

The National Environmental Policy Act of 1979 (NEPA) defined CE as follows:

> "Cumulative impact" is the impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions regardless of what agency (Federal or non-Federal) or person undertakes such actions. Cumulative impacts can result from individually minor but collectively significant actions taking place over a period of time.

In 1982, the Washington Forest Practices Board commissioned a study entitled "Cumulative Effects of Forest Practices on the Environment: A State of the Knowledge" (Geppert, 1984). This study involved a literature review and interviews with natural resource managers conducted over a two year period. For the purposes of that study, the following definition was adopted:

> Changes to the environment caused by the interaction of natural ecosystem processes with the effects of two or more forest practices.

This definition differentiates between effects of forest management which interact and those which do not. Effects which do not interact are termed "individual effects" and are not considered a part of cumulative effects. The Geppert report expands the definition to include effects which are both temporary and persistent.

Major differences between the two definitions are evident. The definition adopted by the FPB deals only with those effects caused by forest practices. The NEPA definition does not specify the source of the impacts but implies the inclusion of all reasonably foreseeable effects on a particular resource or environment.

Although the Geppert definition was developed to meet the objectives of the study requested by the Forest Practices Board, the omission of consideration of non-forest management related impacts is an important one. In particular, when considering the conditions of watersheds which contain land uses other than forest management, it becomes necessary to be able to differentiate between natural variation of watershed conditions, forest management related changes, and other land use effects in order to determine appropriate forest management activities and expected watershed response.

In 1988, the TFW agreement included a process for dealing with CE. This process is:

I) Establishment of resource goals;

2) Management which seeks to attain these goals including anticipation of cumulative effects;

3) Monitoring to check resource status;

4) Adjustment of management based on monitoring.

Several elements of this process are important:

1) Methods for anticipating cumulative effects must be developed;

2) Monitoring methods which can recognize cumulative effects must be developed;

3) Resource objectives (thresholds) must be identified and serve as the basis for monitoring efforts.

Taken together, this implies an integrated system of management and analysis of resources at a level which recognizes cumulative effects to the resource of interest. Through the TF'W process, a watershed level analysis has been identified as appropriate for fisheries resources.

Project Approach to Cumulative Effects

We have adopted the NEPA definition of cumulative effects. This definition allows a broader scope of analysis which includes non-forest management effects on fisheries habitat within any given watershed. The consideration of natural disturbance as well as land and water uses such as recreation, water storage and withdrawal, flood and erosion control, grazing, and agriculture is important because of their influence on the potential quantity and quality of habitat within a stream or watershed.

As described in the NEPA definition, cumulative effects are the result of interactions between several effects. While a number of possible interaction types can be hypothesized, such as additive, synergistic, subtractive (offsetting), or multiplicative, we believe that it is most appropriate to first address the simplest cases (additive and subtractive) in order to build a foundation for addressing more complex interactions. We do not propose to analyze complex interactions (synergistic or multiplicative) in this study.

Two possible approaches to the analysis of CE at a watershed level seem evident. The first approach would be to measure an indicator of the combined effects on the resource of interest, in this case fisheries habitat. An example of this approach might be measuring the riparian canopy opening which is the result of a number of upstream disturbances. From this measure, a determination of the acceptable level of disturbance could be made by policy makers. In this case an indicator, or reaction of multiple impacts, is measured directly.

A second approach is to assess the impacts of the individual disturbances on the local resource and then combine these effects in a calculation of cumulative effects. An example of biological additive effects is the loss of two or more streams to debris torrents which result in mortality to incubating salmonids. In this case, the total impact is derived from the sum of the individual impacts. While there is no direct physical interaction of impacts, there is a cumulative biological impact on the fish within the system.

Both approaches need to be taken in CE analysis. We believe the latter approach is to be preferred for processes which are the result of fairly site specific conditions and which have fairly well defined areas of impact. Example of this are hillslope failures, road failures, and debris torrents. These type of impacts are somewhat analogous to point source pollution.

The first approach lends itself well to watershed impacts which are subtle at any given location on the landscape and which are caused less by site specific conditions than basin or watershed conditions. Examples of these types of effects are hydrological changes caused by vegetation removal and increases in fine sediment inputs to streams due to road construction and road density. These types of impacts are analogous to non-point pollution sources.

This dichotomy of effects is discussed further in our description of an appropriate watershed model (See Table 2.).

Substantial work has already been accomplished to achieve the process outlined in the TFW approach to CE management. Since TFW and the state forest practices regulations implementing TFW must be applied statewide, a flexible process which recognizes natural regional and local variation must be developed. This requires the control of the collection and interpretation of monitoring data so that this variability can be measured and accounted for.

In an attempt to control the collection and interpretation of stream physical habitat survey data, AMSC has developed a five level stream/landscape classification system. The five levels are further divided into sub-units based on physical and biological features which are manifest at the appropriate classification level. These classification levels, the features which define the levels, and the approximate spatial and temporal scale encompassed are summarized in Table 1..

Table (seq table).

Classification Level	Key Features	Spatial Scale (meters) (Minshall, 1988)	Temporal Scale (Years)

Ecoregion	*Climate *Geology	* 10^5	* 10^3 and up
Watershed	*Drainage Basin	* 10^3 - 10^4	* 10^2 . 10^3
Stream	*Drainage	* 10^2 - 10^3	* 101 . 10^2
Stream Segment	*Channel Confinement *Gradient	* 10^2	* 101 - 10^2
Habitat Units	*Depth *Velocity *Substrate · Obstruction Type	* 0.1 - 101	* 101 - 10^2

It is important to emphasize that there are a number of features and processes of the landscape manifest at wide spatial and temporal scales. Identification of these scales is essential in matching watershed feature measurements with the appropriate measurement techniques.

Stream Channel Form and Response

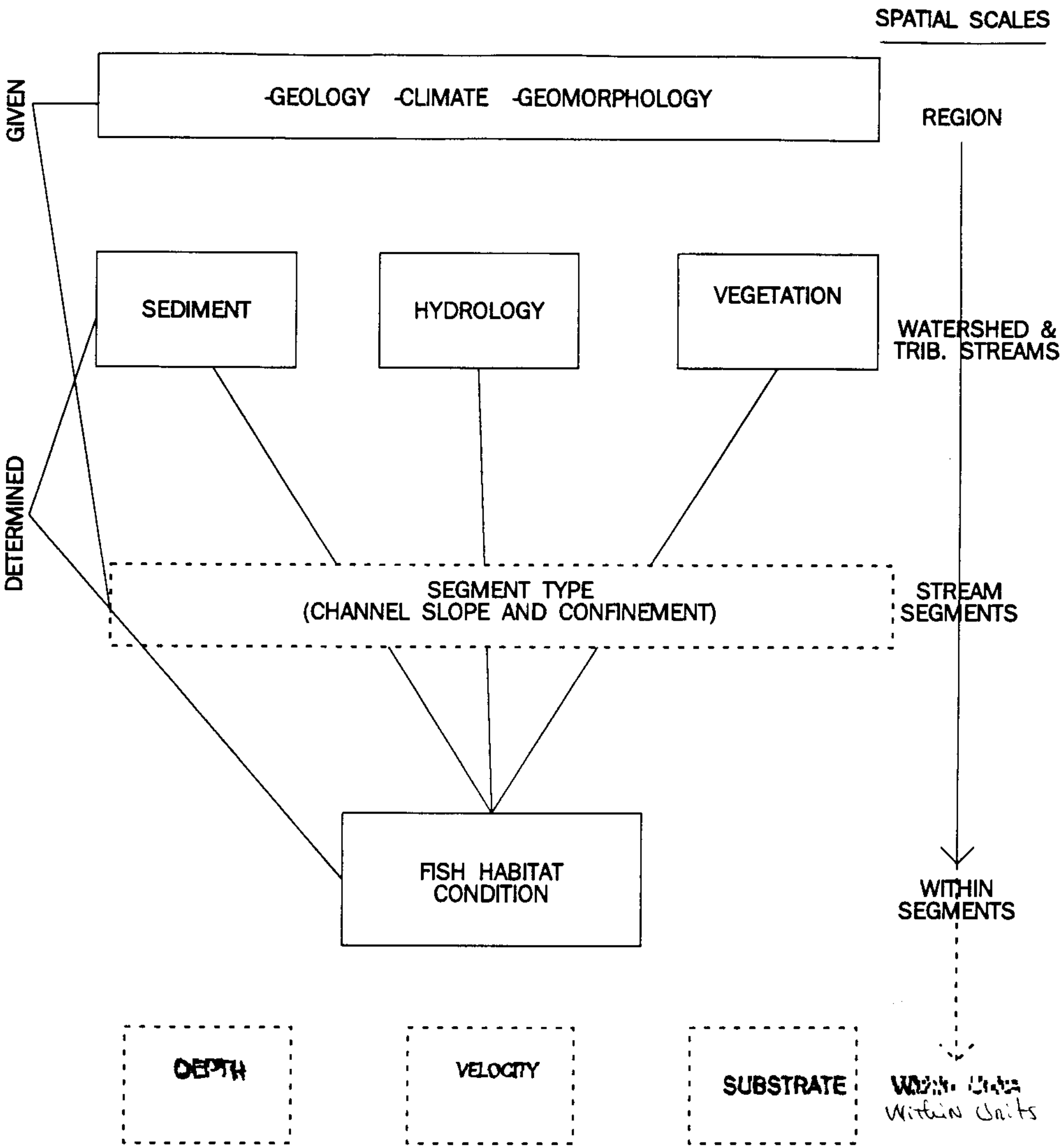
We have chosen to concentrate on morphological channel response as an indicator of fisheries habitat alterations over time. For this reason, we have omitted consideration of water quality and biological processes which can play important roles in determining habitat suitability and use. We believe this approach is most appropriate for this study since morphological changes in stream channels occur at spatial and temporal scales detectable by current remote sensing technologies.

Stream channels can morphologically respond to changes in flow, sediment, and riparian vegetation (Figure 1.). We refer to these as response variables. Changes can be caused by natural events and by land management activities. In general, channel response is predictable but governed by the magnitude of sediment/flow/vegetation change and local channel conditions such as slope, confinement, geology, and vegetation. Heede (1980) provides a good general overview of stream channel response to changes in flow and sediment. Richards (1982) presents a brief discussion of the role of vegetation on channel form.

Forest management can alter watershed hydrology and stream discharge in several ways. Removal of watershed vegetation can reduce rainfall and snow interception and evaporation, increase snow accumulations, temporarily reduce evapotranspiration, and reduce soil water capacity (Harr, 1987)

Interception has been shown to account for 10-35% of annual precipitation with interception of snow often greater than interception of rain (Waring and Schlesinger, 1985) Evapotranspiration will also be reduced immediately following vegetation removal although evapotranspiration rates of young vegetation can exceed the rates of previous mature vegetation within several years (Hart, 1979), resulting in lowered summer flows.

Removal or loss of surface litter through physical disturbance such as log yarding or compaction by ground equipment, or loss through decomposition and lack of litter recruitment, can result in decreased soil water capacity. This can result inquicker attainment of soil saturation and thus faster stream discharge response to storm events.


SPATIAL SCALES
GIVEN
-GEOLOGY -CLIMATE -GEOMORPHOLOGY
REGION
SEDIMENT
HYDROLOGY
VEGETATION
WATERSHED &
TRIB. STREAMS
DETERMINED
SEGMENT TYPE
(CHANNEL SLOPE AND CONFINEMENT)
STREAM
SEGMENTS
FISH HABITAT
CONDITION
WITHIN
SEGMENTS
DEPTH
VELOCITY
SUBSTRATE
Within Units

In general, watershed vegetation removal has been shown to increase average annual discharge, advance flood peak timing, and increase summer flows for several years. These responses are more pronounced in smaller (1-3rd order) watersheds. Responses of larger systems have not been consistently documented (Hart, 1989). Once vegetation becomes reestablished, average annual and summer discharges will generally decrease from previous conditions. Peak discharge timing may not return to prior conditions until vegetation interception capacity is reestablished. In watersheds within western Washington, this may not occur for 15-30 years after vegetation removal.

Loss of interception and evaporation of snow due to canopy removal has been shown to greatly increase snow accumulations on the forest floor. Snow accumulations in clear-cut areas have been documented to contain 2-3 times more water than similar forested areas (Berris and Harr, 1987) These increased accumulations of snow can be subject to rapid melting by warm winter storm events. This results in rapid runoff and increased peak flows relative to prior watershed conditions. In Western Washington, this type of event has been shown to occur in an elevation band termed the transient snow zone. The exact elevation limits of this zone will be determined on a year to year basis by the patterns of snow fall and rainfall. In general, probability of snowfall decreases with decreasing elevation. The probability of precipitation falling as rain decreases with increasing elevation.

Channel Response to Altered Hydrology

Channel sediment transport capacity will increase with increasing flow. The exact relationship between stream discharge and sediment transport is determined by the channel profile which determines flow depth, channel bedform, local scour and deposition, channel slope, and the size distribution of sediment sources available to be transported (Richards, 1982). In the extreme case, a bedrock channel with little or no mobile sediments will simply route water through the channel, resulting in no perceivable changes in profile or material with increasing flow. At the other extreme, highly erodible stream beds will increase their channel cross sectional area until a balance between stream transport capacity and sediment supply are roughly in equilibrium. In the intermediate cases, flow increases will tend to result in the increased transport of smaller bed materials, resulting in a general coarsening of the bed surface material. Channel cross sectional profile may or may not be altered depending on the local erodibility of the banks and bed.

Sediment

Sediment delivery can also be altered by forest management activities. Sediment delivery may increase by surface erosion of roads, skid trails, and other disturbed surfaces. It may also be increased through road failures and hillslope failures. Removal of LWD in stream channel during stream cleanout or through natural attrition can increase the erodibility of streambeds, thereby effectively increasing available erodible sediment. Loss of riparian vegetation and associated root strength can also increase the erodibility of stream banks. In general, all influences of forest management tend to increase the availability of sediments for erosion, however the nature and magnitude of channel response will depend on the magnitude of the increases and channel capacity to transport increased sediment.

Channel Response to Altered Sediment Loads

Channel responses to increases in sediment are also variable depending on sediment transport capacity of the stream, erodibility of the banks, and quantities and size distribution of the sediment being delivered to the channel. In general, the particle size distribution of the stream bed subsurface will be representative of the bedload size distribution. Thus increases in small sediments relative to background bedload will result in increases of fines in the bed subsurface. Increases in sediment delivery which are less than the transport capacity of a particular stream reach will result in the new sediment being transported through the reach without significant change to channel profile within a segment. Local scouring and deposition of these sediments can occur, altering within segment habitat quality.

Sediment increases which exceed the transport capacity of the stream segment will result in deposition of sediments. Deposition within a segment will manifest itself in channel widening and decreases in the average cross sectional depth. In unconfined channels, channel meandering and even braiding may result.

Channels can also respond to removal of external sediment. In general, the stream will transport, to it’s capacity, available sediment. Should sediment delivery to a channel be reduced by some process, the stream will tend to erode it’s banks and bed, to the extent they are erodible. In high gradient channels, bed degradation is favored, leading to constriction and deepening of the channel. In low gradient channels with erodible banks, channel meandering tends to occur with slower downcutting of bed materials.

Vegetation

Riparian vegetation, particularly overstory species, can also be altered in several ways by forest management. It may be removed directly during timber harvest and road construction. Riparian vegetation which is not removed may be subjected to increased probability of windthrow. Vegetation may also be lost or altered during prescribed burning activities.

Once disturbed, overstory vegetation may not attain pre-disturbance conditions for decades or centuries (Likens and Bilby, 1982). The high water availability in riparian zones tends to favor rapid establishment and growth of deciduous species. Reestablishment of coniferous species in riparian zones often follows dominance and decline of a deciduous dominated community, thereby creating longer timeframes for coniferous forest reestablishment in the riparian zone than in adjacent non-riparian forests (Berg, 1990).

Channel Resonse to Riparian Vegetation

Riparian vegetation can serve to stabilize stream banks through root mass integrity and also increase roughness adjacent to stream banks thereby reducing erosive capacity of the stream along the banks (Richards, 1982; Viles, 1988). In channels subjected to flow or sediment increases, presence or absence of vigorous riparian vegetation appears to influence whether a channel will respond by widening or deepening (Platts et al, 1985). Riparian vegetation which enters the channel in the form of large woody debris can also serve to stabilize stream channels, particularly in channels with intermediate to high slope and which are not large enough to move the LWD during normal high flows. In these situations wood in the channel can trap bedload sediments and create a stairstep longitudinal channel profile, reducing local slopes at the habitat unit level and creating a pool/falls habitat configuration. This profile will also serve to trap and stabilize bed materials, reducing the erodibility of the stream bed. Once LWD is removed either through management activities, normal degradation through rot, or by extreme events, bed material can again become mobile and channel erosion and degradation will occur (Heede, 1985). In wider alluvial channels, LWD can also trap some sediments but may also cause local scour and channel migration. The role of LWD in producing local channel morphology heterogeneity has been shown to be an important factor in the determination of habitat suitability and use by resident and anadromous fish species (Bisson et al, 1987).

As previously discussed, riparian vegetation can influence channel bank stability and local channel morphological diversity. Removal of large stable vegetation and associated root masses, and replacement with young smaller individuals, will decrease the stabilizing effect of vegetation on stream banks. This can result in bank erosion and channel widening where banks are composed of erodible material.

Catastrophic Channel Events

The previous brief discussion of channel response to sediment, flow, and vegetation changes is meant to cover normal variation in the environment and management induced change on individual parameters. A second class of events, such as debris flows, debris avalanches, and dam break floods, produces drastic changes in stream channel morphology. These catastrophic events occur naturally in the steep forested basins of the Washington Cascade mountains (Swanson et al., 1982) and in other steep basins around the world (Yoshinori and Osamu, 1984). Effects of these events on channel morphology are the complete removal of sediment and wood stored in the channel for those segments of the stream through which these events travel. Reaching lower gradient stream reaches, this material is deposited in the channel and flood plain

(Benda, 1984). This can result in deposition of large materials such as whole trees **and** large boulders which would not normally be transported during normal high flow events. Effect to channel morphology can thus be permanent since the channel will lack the capacity to erode these materials.

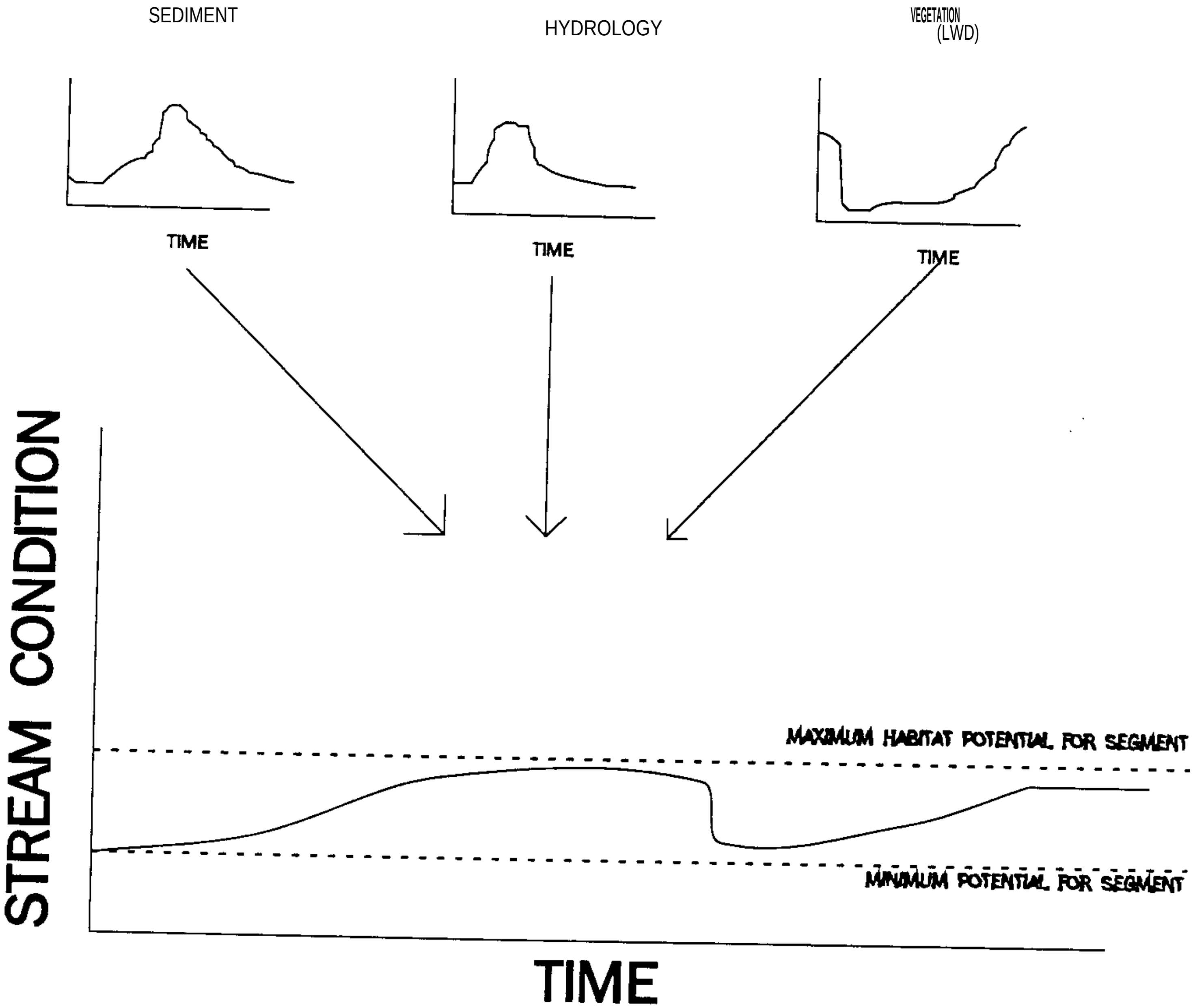
Forest management, particularly timber harvest, has been shown to have the potential to increase the frequency of these events by several orders of magnitude over natural conditions under some situations (Sidle et al., 1985; Swanson et al., 1987).

Temporal Variation (Channel Succession)

The rates of sediment, hydrology, and vegetation fluxes within a watershed, or the interactions between these factors, do not remain constant following disturbance (Swanson et al., 1987). Generalized patterns of recovery from disturbance are depicted in Figure 2. The changes in rates and conditions of the three response variables determine changes in channel condition. These temporal responses of the channel can be characterized as a channel succession. Based on our understanding of long term changes in rates of sedimentation, hydrological regime, and forest succession, it should be possible to predict the response of channel condition.

Trotter (1990) studied the interactions between forest succession and stream succession and found support for the concept of the linkage between stream succession and the geomorphic processes within a watershed. Hedin (1988) and Likens and Bilby (1982) also have documented the correlation between instream woody debris and forest successional state.

A number of researchers have shown the importance of stream channel geomorphology in determining the location, abundance, and stability of woody debris within a watershed (Bisson et al., 1987). In general, the deposition and transport of


SEDIMENT
HYDROLOGY
VEGETATION (LWD)
TIME
TIME
TIME
STREAM CONDITION
MAXIMUM HABITAT POTENTIAL FOR SEGMENT
MINIMUM POTENTIAL FOR SEGMENT
TIME

wood within a channel has strong similarities to the process of sediment deposition. Stability or deposition of wood is a function of the size of the wood and the stream's capacity to move it. Although not a perfect analogy, large wood in small streams will tend to be stable during normal conditions of flow. The same large wood may not reach a stable placement in larger streams and therefore be moved periodically. This general pattern has been observed in Washington streams and forms the basis for riparian leave requirements for streams of different sizes (Bilby, 1986).

Outputs, or toss, of wood and sediment must also be considered. Levels of wood in a channel can be reduced through the processes of downstream transportation and in place decomposition. The importance of downstream transportation will increase with decreasing wood size and increasing stream size. In channel decomposition rates will depend on the size of the wood and the tree species (Bisson et al., 1987).

Wood input to streams is also analogous to sedimentation to streams. Rates of input will be dependent on channel migration, mortality rates of riparian trees, availability of wood in riparian zone, and catastrophic delivery processes such as debris torrents from lower order tributaries and fire.

An understanding of channel succession will require an accounting of changes in inputs and outputs of our response variables, as well as an understanding how fixed factors such as geology, weather, and geomorphic conditions influence the channel response over time. The power of this type of analysis lies in the introduction of time into our model. This satisfies the requirement described by Vlachos (1985) for accounting for the rate and timing of change, and the scale or extent of on-going transformations, in a CE analysis.

Habitat Implications of Channel Response

In order to justify quantification of channel changes as an indicator of habitat quality, we believe it is neccessary to describe the links between fish habitat preferences and channel features. For the purposes of this review, we limit our consideration of habitat utilization and preferences to anadromous and resident salmonid fishes.

Channel changes can be summarized by aggradation, degradation, channel widening or constriction, the fining or coarsening of channel substrate, the stabilization or destabilization of bed and bank materials, and the input, deposition, or loss of LWD. While this is somewhat of an oversimplification of stream response, it serves as a useful model for comparison with fish preferences.

These channel changes will result in changes in the abundance, distribution, and diversity of physical habitat conditions. More specifically, they alter depth velocity and substrate conditions along the stream channel. Our model hypothesizes that changes of depth, velocity and substrate will be uniform throughout stream segments. That is, stream segment type, defined by channel constraint and gradient, will determine the channel response throughout the length of the segment.

At the habitat unit level, fish species and life stages have been shown to have measureable preferences for depth, velocity and substrate conditions. The abundance of species and life stages has been measured exptensively and used to develope habitat preference curves (Bovee, 1978). Data regarding physical habitat preferences offish has been used extensively in both the Instream Flow Incremental Method (IFIM) to model changes in suitability of habitat caused by changes in flow, sediment, and vegetation inputs. Although we are not aware of this method being applied to changes caused by forest management, the concepts involved seem to lend themselves to the types of changes involved.

At the channel segment level, distributions and abundances of fish, and their associated life stages, have also been shown to be correlated to habitat diversity (McMahon, 1983). This data is measured and applied to stream reach or segment levels and best described as habitat complex suitability information. For example, Figure 4. summarizes data regarding the suitability of a stream reach for coho fry based on the percent of pools in that reach. Similar relationships between 16 other habitat variables has been developed for coho salmon of various life stages. Data is also available for chinook, steehead and rainbow trout, and chum salmon. It appears conceptually possible to link changes in watershed condition with channel changes and habitat suitability changes. This approach is summarized in Figure 1.

Anadromous and resident salmonids can be catagorized between those species which have an extended freshwater rearing phase, and those that use freshwater habitats primarily for spawning. This delineation could be usefull for several masons. First, differing freshwater residence times results in differing exposures to some forms of channel change. Second, the freshwater production of the species with extended freshwater rearing stages is condidered to be limited by the amount and availability of rearing habitat. Species with short freshwater residences are generally considered to be spawning limited. An analysis of cumulative effects salmonids must recognize and account for these differences.

Habitat unit suitability data is available for all salmonid species and life stages. Habitat complex data, as previously mentioned, is available for all life stages of at least two rearing limited species and two spawning limited species.

While the testing and validation of this approach is beyond the scope of this study, it could serve as a useful model for watershed analysis which is integrated from the watershed level to the habitat unit level.

Forest practices within watersheds can alter the flux of sediment, water, and large woody debris to stream channels. The resulting adjustments of the channel alters the quantity and quality of fish habitat. These changes can affect the suitability of the new habitat for use by spawning and rearing fish. Extreme events such as debris flows cause the direct mortality of fish.

We have developed a list of types of forest management impacts, and the associated habitat responses, which may be present in watersheds. This list forms the basis for our watershed cumulative effects analysis (Table 2.).

Table 2.

Sources, Attributes, and Habitat Responses to Changes in Three Major Watershed Response Variables

SOURCE	CHRONIC/ACUTE	POINT/NONPOINT	HABITAT EFFECT
ROAD SURFACES AND HILLSLOPE CUTS.	CHRONIC	NONPOINT	INCREASE OF FINES IN SPAWNING AND REARING AREAS
STREAMBANK EROSION FROM ALTERED HYDROLOGY.	CHRONIC	NONPOINT	LOCAL SCOUR AND DEPOSITION. MAY RESULT IN R1 IF SIGNIFICANT FINE SEDIMENT SOURCES ARE DESTABILIZED.

STREAMBANK EROSION DUE TO REMOVAL OF RIPARIAN VEGETATION	CHRONIC	NONPOINT	INCREASED SEDIMENT SUPPLy TO STREAM (R1, R2., R3), CHANNEL .MIGRATIION (R4) OR WIDENING (R5) IF BANKS ARE MORE ERODIBLE THAN BED AND STREAM HAS EXCESS CAPACITY.
ROAD FAILURES.	ACUTE	POINT	CHANNEL CAPACITY ADJUSTMENTS THROUGH WIDENING OR SCOUR.
HILLSLOPE FAILURES.	ACUTE	POINT	CHANNEL CAPACITY ADJ.

HYDROLOGY

VEGETATION REMOVAL (NOT IN TRANSIENT SNOW ZONE)	CHRONIC	NONPOINT	SHORT TERM INCREASE IN TOTAL DISCHARGE AND SUMMER LOW FLOWS, FOLLOWED BY REDUCTION OF SUMMER LOW FLOWS.

VEGETATION REMOVAL (TRANSIENT **SNOW** ZONE)	CHRONIC **(20-30 YEARS)**	NONPOINT	MAY RESULT IN ORDER **OF** MAGNITUDE INCREASE IN CHANNEL PEAK FLOWS. RESULTING IN SCOUR OF BED AND BANKS, **DE-**STABILIZATION OF BANKS, AND LWD REMOVAL,

VEGETATION

HARVEST IN RIPARIAN ZONE	CHRONIC	POINT	DOMINANCE OF DECIDUOUS TREE SPECIES FAVORED BY MOISTURE. MAY LEAD TO LONG TERM DEFICIT OF DECAY RESISTANT LARGE CONIFEROUS WOODY DEBRIS INPUT TO STREAM CHANNELS, REDUCTION OF HABITAT DIVERSITY AND SUITABILITY.

HARVEST IN RIPARIAN ZONE.	CHRONIC	POINT	STREAMBANK DE-STABILIZATION AND EROSION FROM LOSS OF ROOT STRENGTH.
REMOVAL OF RIPARIAN VEG. BY DEBRIS TORRENTS.	ACUTE	POINT	STREAMING DESTABILIZATION AND LOSS OF LWD SOURCE. ALSO REMOVAL OF LWD FROM CHANNEL RESULTING IN REDUCTION IN HABITAT DIVERSITY.
DEPOSITION OF LWD BY DEBRIS TORRENTS	ACUTE	POINT	SOURCE OF LWD TO CHANNEL.

Our watershed model includes response variables, and identification of spatial and temporal scales associated with these variables

This list of response variables and associated habitat changes provides a structure for analysis. The next step is to determine the appropriate ways of measuring these features.

REMOTE SENSING OF RIPARIAN AND STREAM HABITATS

Overview

Remote sensing has been shown to be an effective technique for many monitoring and inventory purposes, particularly for forest and land use determination. Comparatively, its use in stream and riparian monitoring appears to have been limited.

Greentree and Aldrich (1976) used large scale aerial photographs to identify and quantify trout and riparian habitat in a portion of Hat Creek in Northern California. They used low level fixed wing aircraft flights to produce color and color infrared (CIR) photos at scales of 1:600, 1:1584, and 1:6000. They found that instream habitat features such as pools, riffles, debris, and aquatic vegetation were easily identified and quantified. Substrate type and size were also identifiable where the water surface was smooth and the bottom was not obscured by riparian vegetation. Riparian vegetation was identifiable and growth which occurred between 1968 and 1969 surveys was quantified. Water depth was also estimated using both parallax and optical density techniques. Parallax methods require the use of stereo pairs of photographs. Optical density techniques use the density (darkness or color) of a photograph as an index of water depth. Optical density analysis resulted in good density/depth correlations in smooth water. Parallax and rough water calculations were not as effective although surface turbulence was useful in determining velocity classes. It was also found that the 1:600 scale was preferable for assessing instream features while 1:1584 was preferable for riparian analysis. Color infrared was preferred for vegetation analysis while color yielded the best information on bottom types. They concluded that aerial photographs could be a valuable aid in assessing stream habitat. It should be noted that this study took place on an open canopy stream of low to moderate gradient and excellent water clarity. Stream width exceeded 100 feet at some points along the 3.5 mile study section.

Culpin (1978) also documented the ability to identify and quantify instream habitat and riparian features. He evaluated the use of 35mm CIR and color photos taken from two platforms, a fixed wing aircraft door mount and fixed wing aircraft floor mount. Photos were taken of portions of the Rio Grande and Red rivers in New Mexico in 1975. Scale was not stated but flight altitude was 2000'. Ground truthing was conducted prior to the flights and linear ground distances between prominent features were measured in order to establish scale. Culpin concluded that the floor mount was preferable to the door mount due to the ability to sight through the camera range finder. He also felt that while the 35ram format was economical, its small size and the large number of photos needed to cover the study area made it inconvenient. He also recommended larger format also for ease of interpretation. CIR gave good water penetration when slightly overexposed and resulted in the clearest delineation of riparian vegetation. The color film combined with a Wratten 3 (yellow) filter also provided good penetration but was less suitable for riparian interpretation. Features clearly interpretable were stream shade, upper bank condition, stream bank stability, and percent bottom silt.

The Handbook of Remote Sensing in Fish and Wildlife Management (1979) includes an extensive bibliography and literature review. It contains documentation of the feasibility and utility of using remote sensing for wildlife habitat assessment, limited mostly to terrestrial habitats (excluding riparian areas), or population census of wildlife. The section on monitoring of riparian habitat is one paragraph long and contains five literature citations. These cited studies focused on the assessment of riparian vegetation identification in predominantly arid range and agricultural settings. The document concludes that remote sensing is a viable tool for riparian area monitoring and inventory.

The Handbook also contains an extensive section on remote sensing of wetlands, lakes, and even oceans. The assessment of river and stream habitats is argued to be feasible and is supported by five literature citations.

Culpin (1985) and Culpin and Baston (1985) also documented the use of large scale aerial photos for riparian area inventory and monitoring. They used 1:2000 CIR photos to document riparian variables such as vegetation type and sub-type, riparian area width and acreage, plant species composition (trees and shrubs), ground cover, vegetation density, reproduction, vegetation trend, and structure. Stream variables including streambank shade, stream width, floodplain width, streambank stability, streambed silt, and stream channel stability have also been shown to be interpretable. Features which they believe do not lend themselves to identification at this scale are plant species composition (grass and forbs), vegetation condition class, and vegetation potential. They suggest that aerial photos combined with ground data can be used for riparian baseline inventory including identification of stream/riparian segments and existing conditions of stream/riparian areas.

Culpin et al (1985) have also documented the utility of combining aerial CIR with ground data to yield a data base with more information than either method provides alone. They used both ground data and I: 2000 CIR photos in a study of grazing systems along Tabor Creek in Nevada. They found that stream width and depth, canopy cover, streamside habitat type, streambank stability, overhanging vegetation, and stream bank alteration could be measured and interpreted from the aerial photos. Variable measured on the ground were substrata, substrate embeddedness, bank-stream contact water depth, pool width, pool depth, riffle width, streambank angle, streambank undercut, light intensity, stream profile, stream gradient, stream velocity, and fish species composition, number, and biomass. They also used aerial photos from successive years to identify areas where significant channel and vegetative change had occurred and more detailed analysis was warranted.

Recent work by Grant (I 988) in Oregon has documented the use of standard USFS **1:** 20000 black and white, color, and CIR photos for detecting and quantifying changes in riparian and stream channel characteristics. The features seen at this scale are used to document changes in riparian canopy opening caused by changes or unusual incidents of flow, sediment supply and transport, and woody debris supply and transport.

Grant identified several problems in using aerial photos for assessing conditions in small to medium streams in the Pacific Northwest. Steep hillslopes, dense riparian cover, and shading effects make it difficult or impossible to see the actual stream channel. Even in open canopy areas, Grant argues that the small scale of most available aerial photos taken for forest management purposes does not lend itself to interpretation of in-channel features of small to medium sized streams. In response, he has developed a technique to interpret riparian features which are more appropriate at the scale of 1: 20000. This technique is called RAPID (Riparian Aerial Photographic Inventory of Disturbance).

The RAPID technique uses the changes in the width of unvegetated streamside cover (riparian canopy opening) as an indicator of major channel disturbances. A detailed method for quantifying these changes is presented. Basic theory and interpretation of causative factors is also presented. While it is clearly demonstrated that these changes in riparian canopy opening can be identified and quantified, the method stops short of allowing an interpretation of instream features such as pools, fifties, channel stability, and substrate.

Practical Considerations

In considering the potential usefulness of aerial remote sensing for stream and riparian inventory and monitoring, there are a number of physical and technical issues which must be taken into consideration. These issues determine the feasibility and practicality of aerial remote sensing for these purposes.

Factor of Scale

A fundamental question which must be decided prior to use of remote sensing concerns the appropriate image scale and resolution for the intended use (Woodcock and Strahler, 1987). This is determined by several factors including the size and nature of the elements you wish to monitor, the spatial resolution of the image, and the practicality of obtaining data at a particular scale and resolution.

The elements of primary consideration for assessing aquatic habitat for fish are related to the channel size. Presently habitat is defined by a number of within channel morphologic features. These include channel unit types(pools, riffles, cascades, etc.), unit widths, depths, and areas, channel bank stability, instream and streamside cover, substrate, and other factors (AMSC, 1989). These features can be identified in large scale aerial color and CIR photographs (Culpin, 1985) hut sometimes not from smaller scale photos (Greentree and Aldrich, 1976; Grant, 1988).

The appropriate scale will also be somewhat affected by the recording medium. Differing media result in images with different spatial resolution. For example Landsat MSS images have an 80 meter resolution, TM has a 30-m resolution, and SPOT images have a 10-m resolution. Problems arise when the features of interest are smaller than the resolution size of the image. This limits the usefulness of satellite imagery for riparian and stream monitoring in smaller watersheds. Mid level photos (1:20000) taken with B&W, color, and CIR films generally do not have sufficient resolution to allow interpretation of features in smaller streams but can be used for riparian area analysis.

Video images may also be constrained as their resolution is poorer than film based images (Meisner, 1986).

Finally, there are practical considerations about obtaining images of a particular scale. The scale of existing aerial photography used in forest land management is generally from 1:12000 to 1:20000. If non-traditional scales are required, the cost and feasibility of acquisition must be taken into account.

Phvsical Constraints

Physical constraints such as canopy, slope and other factors may limit the ability to detect features of interest. This is particularly a problem in the wetter areas of the northwest where streams are located under closed canopy riparian areas or within geomorphic features such as canyons. This has led to the approach used by Grant (1988) which focuses on interpretation of visible features such as riparian canopy opening as they might relate to in channel features.

Expense

In any monitoring or inventory planning, cost is obviously a major consideration. Studies generally have concluded that the cost of remote sensing will usually be less than ground survey data (Lillesand and Kieffer, 1987; Janza, 1975). Incorporating remote sensing into existing and future forest/watershed management programs within Washington State could greatly enhance our ability to inventory and monitor aquatic and riparian habitat.

Sensors

The literature indicates that there are several different image sensors which are well suited for monitoring riparian and aquatic systems. We have chosen to focus this discussion on sensors which might be well suited to the particular aerial remote sensing problems encountered in Pacific Northwest forests, specifically heavy or closed canopy and small streams.

Extensive literature exists regarding the use of photographic equipment for remote sensing of natural resources (Lillesand and Kieffer, 1987; Janza, 1975; Lo, 1986). This sensor technology has several characteristics which make it desirable for remote sensing of aquatic and riparian habitats. These include high effective resolution, highly developed photogrammetric techniques, easily acquired equipment and materials, a number of film formats, and relative low cost of camera equipment as compared to non-photographic methods such as video.

There are also several disadvantages to this media such as development costs, development time, narrower spectral response than video or other electronic sensors, and images which are not digital in nature so that they are not readily suitable for computer assisted analysis.

Examples of recent use of this medium include the analysis of canopy closure (Grant, 1988), and stream/riparian inventory and monitoring (Culpin and Baston, 1985).

The use of video for acquisition of natural resource information has been developed and tested, particularly in agricultural and rangeland settings. Meisner (1986) describes the essential elements of an airborne video system and the conditions and means by which video may best be used in aerial applications. He also describes several advantages and disadvantages of video imagery. Advantages include the immediate availability of the imagery, the ability of the operator to see a live image as it is being acquired, the electronic format which makes computer processing and interpretation feasible, and the low cost of video tapes as compared to film and development costs.

Meisner (1985) listed disadvantages of video as low resolution relative to photography, lack of stereo coverage, and high equipment acquisition costs. Resolution of video is approximately 1/3 that of 35mm photography (approximately 250-350 pixels across field of view for video as opposed to 720 pixels for 35mm). This can be a problem and is directly related to image scale and feature size. Stereo views can be generated using overlapped video images but again may be limited by poor resolution. While the cost of video equipment may still be higher than for standard cameras, the estimated cost of video, equipment ($12-13, 000 in 1985) presented by Meisner is no longer valid. A camera and recorder can be purchased for $1-4,000 depending on requirements.

The issue of resolution must be considered carefully. Effective pixel sizes of 2’ are possible at altitudes of 341 feet with a 6mm lens focal length. Resolution may not be a significant factor for very large scale images.

Video can also be used for generating CIR and false color images (Meisner and Lindstrom, 1985; Everitt and Nixon, 1985). As previously described, CIR images are preferable for water penetration and vegetation differentiation characteristics. False color images generated from filtered B&W cameras can duplicate these advantages and may offer other image interpretation opportunities (Everitt and Nixon, 1985).

Existing applications of airborne video are rangeland studies (Everitt and Nixon, 1985), crop damage (Escobar et al, 1983), soil surface conditions (Everitt et al, 1989), and forestry (Meisner, 1985). Gerten and Wiese (1985) compared computer assisted video image interpretation with manual interpretations of lodging winter wheat and found that manual versus computer estimations varied from 7-10%.

Multispectral and other Electronic Media

A number of other electronic sensors have been developed. Multispectral scanners, which are commonly used in satellite systems, are extremely effective for vegetation, soil, and water reflective analysis. These scanners are also available for fixed wing aircraft and other platforms. The data collect is digital, allowing computer analysis. The multi-band/multi-spectral nature of the data allows great flexibility in data analysis and interpretation.

The major limitations of satellite data is resolution (see next section) and the need for extensive ground survey data for verify image classification results. Costs of obtaining this type of equipment for use in aircraft for larger scale applications is high.

Microwave (radar) remote sensing techniques have been developed extensively in the past few years. Radar has the advantage of being able to penetrate atmospheric conditions such as clouds and smoke, and the reflective properties of terrestrial features are much different for microwave than visible or thermal radiation (Lillesand and Kieffer, 1987). These images are particularly well suited to terrain analysis. Disadvantages are expense and lack of ability to distinguish between vegetation types.

Thermal scanners are also available. These are, by their nature, best suited to applications involving features which exhibit different thermal radiation properties. They may be useful in delineating thermal gradients due to the presence or absence of hyporiec zones although we have not found literature describing this use.

A number of sensor platforms which are suitable for riparian and stream monitoring have been developed. Since streams are fairly small geomorphic features on a global perspective, but are sensitive to the conditions of the larger surrounding landscape (Heede, 1985), data from a range of spatial scales and resolutions may be appropriate.

Satellite

As previously discussed, satellite imagery is generally of small scale and low effective resolution. Landsat MSS images are taken at an scale of hi,000,000 and resolution of 80 m. TM data have an effective resolution of 30 m. The newer French SPOT satellite images have an effective resolution of 0 m. However, the broad image coverage and multispectral sensors used provide opportunities for analysis of large features such as watersheds and physical and biological features which may be differentiated based on their reflective characteristics.

Connors et al. (1987) have demonstrated the feasibility of classifying geomorphic features and landscape stability using SPOT imagery. They were able to differentiate these features based on landscape position, geomorhpic process type, soil type, vegetation cover, and slope. Use of Landsat data for land use and cover is also well established (Lo, 1986). The multispectral sensors and large scale of data can complement information taken from other platforms or ground surveys (Lillesand and Kieffer, 1987).

Fixed Wing Aircraft

Fixed wing aircraft are probably the most widely used remote sensing platform. They have been used successfully for obtaining images from altitudes ranging from less than 100 ' (Ultralight) to 60,000' (U-2). They may be used with any type of sensor. Cost will vary depending on the aircraft and application As, previously describe, fixed wing aircraft are excellent for obtaining images on riparian and larger open canopy streams. They are limited by their lack of ability to fly at very low altitudes in areas of high topographic relief.

Unconventional fixed wing aircraft have been tested. Treadwell et al (1985) used ultralight aircraft for wildlife habitat surveys in Burkina Faso. They found that this aircraft was an effective platform for large scale (1:200 - 1:3,000) photos. Advantages of this aircraft are low capital cost, low maintenance, transportability, and lack of government regulation in many countries. Disadvantages found were poor performance/safety in turbulent conditions, lack of parts availability, limited traveling distance and flying time and need for hangar space to protect craft from weather and sunlight. 35mm dual camera arrangements were used but video was also tested and found to be suitable for assessing habitat.

Helicopter

Although the helicopter would appear to be a suitable remote sensing platform, we found no literature describing its use. I believe that favorable characteristics would be maneuverability and ability to hover or travel at slow speeds. Speed could be an important factor if using video sensors since image blur is an inherent problem due to the standard 1/60 second "shutter speed" used in many video systems. Drawbacks would include the high cost of helicopter flight time as compared to fixed wing aircraft. The potential of this platform needs further assessment.

Balloons

Balloons have been used for a number of applications. Lillesand and Kieffer (1987) credit the first aerial photographs (1860) to this platform. Janza (1975) devotes several pages to various balloon types, their performance characteristics, and applications. Desirable characteristics of balloons are the stability of free floating balloons, the ability to tailor the balloon size and shape to the application, the low cost, and ability to attain high altitudes. Undesirable characteristics include effects of wind speed and weather, response to temperature, and the lack of control of free flight balloons.

Three basic types of balloons are free flight, tethered, and powered. Tethered and powered balloons have potential usefulness in remote sensing of riparian and Stream systems. Basic balloon shapes are natural, spherical, and formed (such as blimp shaped).

Janza describes only one application of a powered balloon. It was launched by the U. S. Airforce and was powered by a battery driven slow speed motor. It was 710, 000 cf in volume and rose to an elevation of 60,000 ft. The nature of the sensor and the purpose of the flight were not given. The ability to remotely control and guide the balloon along a path or flight line are advantages of a powered balloon over a tethered or free flight balloon.

Tethered balloons have been used more extensively. Advantages of tethered balloons are greater stability in higher wind conditions and ability to control the location of the balloon. Tether configurations may be single, dual, or tri-tether and may serve the dual purpose of carrying an antenna, power line or communication line. Tether weight must be considered in determining the size and payload of the balloon.

Meyers and Meyers (1985) used a tethered blimp-shaped balloon to obtain aerial photos of archaeological sites on the Island of Crete. Their balloon was 33 feet in length and had four stabilizing fins. Dual tethers were used. The mounting of, two cameras allowed the use of two different film/filter configurations at one time. The cameras were triggered by an FM radio band remote control system.

I have received verbal information that balloons have been used in both British Columbia and Oregon for photographing streams, however I have not yet been able to verify or find reference to this technique in the literature.

Past remote sensing applications to riparian and stream monitoring and inventory, and the capability and potential of the technology, indicate that it has great potential to assist in the TFW monitoring and research program and in watershed screening and analysis. The recognition by the Ambient Monitoring program that forest resources and landscape processes are operating at a number of spatial and temporal scale parallels the development of remote sensing technology from tethered balloon(large scale image for observing small scale features) to Landsat and SPOT satellite imagery (small scale imagery/large scale processes).

It is clear that the issue of scale is very important and should receive careful attention prior to the implementation of any method using remote sensing technology. Our model of key biological and physical features of watersheds includes features that encompass spatial scales differing in many orders of magnitude. Thus, we must determine which features are essential for inclusion in any watershed analysis and match the capabilities of the available remote sensing techniques to the appropriate spatial scales. This is equally true of temporal scales at which many watershed processes work.

Although data derived from any remotely acquired source such as aerial photography or satellite imagery will at best span a period of several decades, features visible in this data may be interpreted and long term processes leading to the current condition of those features be inferred.

METHODS

Overview

Our approach to characterizing watershed and stream channel cumulative effects is based on Grant's RAPID analysis with several modifications. As previously discussed, RAPID quantifies riparian canopy opening and documents "initiation sites" such as lateral and landslides, road failures, and clear cuts. While this type of analysis identifies the presence of sediment sources, and the presence or absence of vegetation removal which might affect stream and watershed hydrology, it does not quantify these features. RAPID also does not assess the riparian zone conditions which we believe is a prime determinant of channel response to sediment and flow changes and to the long term succession of in channel habitat features. RAPID does not directly account for channel morphological features such as slope, confinement, and size which will also limit the possible channel responses to altered sediment, flow, and vegetative conditions within the watershed. The RAPID analysis also does not attempt link riparian canopy opening directly with in-channel habitat conditions. Each of the aforementioned attributes have been identified as being an important component of our watershed cumulative effects response model.

In order to address these discrepancies, we are mapping in digital form the following from 1:12,000 and 1:40,000 aerial photographs:

1) Riparian Canopy Opening
2) Riparian and terrestrial vegetation types and successional stages
3) Roads

4) Landslides and other visible erosional features

5) Channel units when visible (open canopy streams)

6) Channel gradients

7) Topographical features of selected sub-watersheds

8) Hydrography

In addition, we are mapping and digitizing, or obtaining existing maps in digital form, for the following attributes:

1) Soils

2) Geology

3) Public Land Survey

As stated in the goals of the project, our purpose is to explore quantitative relationships between instream habitat and changes in sediment, hydrology, and vegetation within a watershed. The data being collected encompasses measurement of the response variables and fixed features described in our watershed model. It is our intent in the final report to describe the strenghts and weaknesses of the approach we have taken and to recommend an appropriate method for watershed screening using remote sensing.

Analysis of aerial photographs is being performed by two methods:

1) Manual or non-machine assisted photogrammetric techniques and;

2) Analytical stereoplotter or machine assisted techniques.

Manual techniques involve quantifying parameters of interest through direct measurement from aerial photos. This measurement involves determination of scale of photograph, the measurement of features of interest on the photos using dividers and ruler, and the conversion of photo measurements to ground measurements by multiplying the photo measurements by the photo scale.

Accuracy and precision of this method are determined by the scale of the photographs, changes in scale within photographs due to topographic relief, and precision of measurement device. Accuracy of aerial measurements for some features such as riparian canopy opening width is difficult to quantify due to lack of method to measure during ground surveys. In the case of riparian canopy opening, we are using canopy densiometer measurements as a surrogate.

Machine assisted (analytical stereoplotter) photogrammetry involves several steps.

l) Relative orientation in which stereo pairs of photographs are controlled or oriented to adjacent stereo pairs to form a "stereo model" and;

2) Absolute orientation in which the stereo model is orientated to known ground coordinates. Once the stereo model is established and oriented, all physical features visible in the photographs can be described in three dimensions (x,y, and z) in real units such as feet or meters.

Digitization of features from photographs.

Data collection using the stereoplotter involves digitizing points which describe, or outline, the features of interest in the photographs, such as roads, vegetation boundaries, or streams. Points are stored in digital form and may be input directly into computer assisted design (CAD) or geographical information system (GIS) computer systems.

The stereoplotter being used for this project is an AP190 manufactured by Carto Instruments and owned by the U.S. Forest Service. It is located at the U.S.F.S Pacific Northwest Research Station (PNW) office in Bloedel Hall, University of Washington. This stereoplotter is a PC based opto-mechanical machine. AP190 accuracy has been shown to be better than 20 microns which corresponds to a ground distance of 2 ft. on a 1:32,000 scale photograph (Warner, 1990). It has also been shown to have a planimetric accuracy of 76 cm and a spot height accuracy of 46 cm when used with 1:15000 black and white prints (Warner, 1988).

A principal advantage of the AP190 is it's ability to generate digital terrain models (DTM's). Warner (1988) documented the use the AP190 by the Norwegian Institute for Georesources and Pollution Research (GEFO) to generate topographical maps from 1:10,000 scale 35 mm aerial photographs. The DTM's had spot height accuracies of 70 cm. This information was used to develop aspect and slope length data for use in a soil erosion model.

This AP190 is designed to be low in cost and suitable for use by non-specialists. Proficiency at using the instrument can be acquired through several days of training, provided the operator has the ability to perceive the stereo effect provided by stereo photographs. For this project training has been provided by Steve Reutebuch of the PNW.

Ground control of the stereo models was accomplished by obtaining control data from the Washington Department of Natural Resources Map and Photo Center. Control data was available for 1985 1:40,000 photographs. This photo set has been the basis for the initial data layers developed for the DNR's GIS system. Using the same control data in order to orient our 1:12,000 photographs ensures compatibility with DNR GIS data layers. Had such data not been available, our stereo models could have been oriented using existing maps (Reutebuch and Rhea, 1988), however achieving compatibility with existing DNR GIS data layers would have been more difficult.

We are currently in the process of completing control of the photographs and digitizing watershed features. GIS data layers derived from other sources have been manually digitized or acquired in digital form.

Stream survey data was collected during August and September of 1990. Table summarizes the locations surveyed. The AMSC physical habitat survey method (AMSC, 1990) was used in most cases. Additional survey work was performed in the Hob and Mashel using a modified survey method designed to complement the measurement increment used in the RAPID technique. Channel width, depth, slope, canopy opening, riparian vegetation, and LWD presence were measured at 100 meter increments beginning at the downstream boundary of a channel segment.

For each study area, the most recent available photographs are being used to develop maps of "current" conditions. In addition, several sets of historic photo series are being used to quantify rates and magnitudes of change in watershed attributes. Photo sets being analyzed are summarized in Table 3.

Table 3.

WATERSHED	YEAR	SCALE	TYPE

Hoh River	1960	1:12,000	B&W
	1971	**1:12,000**	B&W
	1983	1:40,000	B&W
	1990	1:13,000	Color, B&W
Mashel River	1983	1:40,000	B&W
	1965	1:12,000	B&W
	1978	1:12,000	B&W
	1985	1: 12,000	B&W
Taneum Creek	1985	1: 12,000	Color
	1980	1:40,000	B&W
	1979	i: 12,000	B&W
	1964	1:20,000	B&W

For each photo set, the following features are being digitized utilizing the AP190:

* Riparian zone boundaries

* Riparian and terrestrial vegetation type and succesional stage

* Riparian canopy opening

* In channel features including pools, riffles, and LWD where riparian canopy opening allows

* Lanslides, road failures, and other erosional features (location, size, volume)

* Channel cross sections at randomly selected locations within randomly selected segment types

* Roads

Features being measured by manual techniques are:

* Riparian canopy opening as prescribed by RAPID technique (Grant, 1985)

The features selected for measurement represent the major response variable sources and channel response outlined in Table 2.

TANEUM CREEK PHYSICAL HABITAT SURVEY ANALYSIS

PRELIMINARY SUMMARY FOR TFW CONTRACT

WATERSHED ANALYSIS - CHANGES IN INSTREAM AND RIPARIAN HABITAT THROUGH TIME

JUNE 24, 1991

TANEUM CREEK. KITTITAS COUNTY. WA,

East of the Cascade Crest there is a different geology, climate and land-use history than generally found in western Washington. Therefore, watershed analysis methods developed for conditions normally encountered in western streams may not be applicable to eastside sites. For instance, many of the eastside river basins were dominated by agricultural practices such as grazing and crops prior to the major logging entries. As a result of agriculture, water diversion and canal systems were established in the late 1800’s, controlling discharge in the lower basins since that time. In addition, the drier climate produces different vegetative complexes and different hydrologic regimes which must be considered when analyzing the watershed. In order to address the different land-use practices and watershed conditions seen in the Eastern Cascades, Taneum Creek, a tributary to the Yakima River, was included in the "Watershed Analysis" project.

Taneum Creek is a fourth order tributary to the Yakima River. It meets the Yakima at R.M. 166.1 mile in Kittitas County near Thorp, WA. The Taneum drainage extends about 25 miles from Lookout Mountain(elev. 5800') and Quartz Mountain (6000') to it's confluence with the Yakima at elev. 1,100'. It has an approximate drainage area of 75.3 sq. mi. with two major tributaries, the north and south forks, which have drainage areas of 23.7 and 22.1 sq. mi., respectively. The lower basin is dominated by willow, cottonwood and lodgepole pine. The vegetation gradually changes from a lodgepole-tamarack complex to a Douglas fir complex as elevation increases.

Hydrology:

The hydrologic regime of Taneum is typical for eastside systems. Peak flows (101 - 300 cfs) occur from May to June due to winter snowmelt. The peak rises and falls very quickly. Minimum flows (5 - 10 cfs) usually occur in August and September. Another small peak may occur in November or December with the corresponding to an increase in rain. Average annual flow is about 82.9 cfs. The headwater areas receive almost two times the average precipitation as the lower basin. This is reflected in the greater density of vegetation in the upper watershed.

At the mouth of the creek, and through the broad flat lowland area of the basin, the area is predominantly Holocene alluvial deposits consisting mainly of basalt sands and gravels with some glacial outwash. Through the middle portion, which alternates between canyon and meadow areas, the geology is dominated by Columbia River Basalt lava flows with some sedimentary interbeds. However, on the north side, an outcropping of the Ellensburg Formation, Miocene sedimentary rocks, forms the upslope area. Again laid down in the valley bottom past the Taneum canyon area, the alluvial deposits appear. The remainder of the watershed past the confluence of the north and south forks is predominantly metamorphic and granitic bedrock with some sandstone, shale and old lava deposits. There is another small lens of the Columbia Basalt that cuts through the upper ends of both tributaries.

The basalt lava flows contributed heavily to the constrained nature of the stream channel in the middle section of the mainstem. Large outcroppings of basalt pinch the stream channel and limit the growth of riparian vegetation. In contrast, the areas dominated by alluvial deposits have wider valley floors and the stream channel exhibits a greater sinuosity and complexity. The headwater areas that run through the bedrock areas tend to be steep, narrow and incised.

Land-use History:

The Taneum Creek area was not inhabited by settlers till around 1868 when several families established homesteads and began farming wheat and hay and grazing sheep and cattle. The major change came when the Taneum ditch was completed in 1873, diverting most of the water and creating a fish passage barrier about 1.5 miles above the mouth of the creek. Agriculture still exists today and several more diversions are in place that successfully divert at least 90% of the water out of the lower portion of the stream 10 months out of the year.

Around 1890, the North Pacific Railroad came into the Yakima Valley area to service the agricultural community. Shortly thereafter in 1903, Cascade Lumber Co. began operations in the area. Several sawmills and a boxmill were established on the creek. A spur rail track was built up the Taneum in 1928, but was only operated through the mid-thirties. The first major logging effort was launched by Cascade in 1956 and continued through 1968. Logging was continued in the mainstem area until recently and the private timber lands in the headwaters have been cut over in the last five years. Portions of the south fork remain as old growth.

The other major uses in the area are recreation, camping, hunting and off-road vehicle use. The first two miles of the area are still under private ownership and remain in agriculture. The next six miles are within the L.T. Murray wildlife refuge and are open for recreation use and serve as winter elk range. The upper watershed is under checkerboard ownership between the Wenatchee National Forest and Plum Creek Timber CO.

There is an abundance of beaver activity throughout the drainage. Beaver have created significant impoundments in the channel and in the adjacent valley bottoms. None of the dams present are passage problems and many of the pools created have good vegetative cover, but are also heavily silted. Elk are the other major wildlife species in the basin. In the summer they range fairly high in the watershed, but in the winter they move into the wide valley at the bottom of the basin. Evidence of browsing is significant.

Stream surveys:

In August 1990, 10.7 miles of the mainstem of Taneum Creek were surveyed using the Ambient Monitoring (AMSC) stream survey protocol (Ralph, 1989). An additional, 8 miles of the North Fork of Taneum was surveyed by other TFW crews. Previously in 1989, AMSC surveyed about 3 miles of the South Fork of Taneum Creek and several miles of the mainstream using the same protocol. A valley segment breakdown (Table 1.), horizontal control survey, habitat unit breakdown and riparian vegetation survey were all completed for the 10.7 miles of the main stem that were surveyed in 1990. In addition, several other substrate analysis parameters and channel geometry measurements were taken in order to duplicate historical stream survey data collected in 1936 by the U.S Bureau of Sport Fisheries (now the U.S. Fish and Wildlife Service). Extensive riparian canopy cover and canopy opening widths were measured throughout the survey in order to field check and compare with subsequent aerial photo analysis of riparian vegetation.

TABLE 1.

VALLEY SEGMENTS:

Taneum Creek Main Stem:

Reach #1	F3 - Wide Alluviated Valley Low gradient, 0.5 % grad.	1.5 mi.
Reach #2	M2 - Alluviated, Moderate	5.3 mi.

Slope Bound Valley, 1.8% grad.

Reach #3	V4 - Alluviated Mountain Valley, 1.6% grad	2.3 mi.
Reach g4	V4 - Alluviated Mountain Valley, 2.8% grad.	**1.6 mi.**
		10.7 mi.

Note: The survey was started approximately 1.5 miles above the confluence of the Creek with the Yakima River.

Historic Survey:

Starting in 1936, the U.S. Bureau of Sport Fisheries began systematically inventorying pool and substrate characteristics in the majority of tributaries within the Columbia Basin in order to document stream habitat conditions for salmonids. Pools were classified by different size and depth criteria, while substrate was divided into size classes. This information was collected every 100 yards for each stream and river in the survey.

Taneum Creek was one of the first streams to be surveyed in 1936. Five reach stations were set up along the main stem starting at the mouth of the Creek. Reach breaks seem to be established at landmarks or areas with easy access. Width, depth, flow and temperature were taken at each station then every 100 yards the habitat data was recorded. All diversions, passage problems, tributaries and other significant information was recorded, similar to the present day survey. Since pools and spawning size gravels are two of the critical components of salmonid fish habitat, the most useful information is the pool frequency data and the percentage breakdown of substrate sizes.

This unique historic information lets us make a make a direct comparison with the 1990 survey data and calculate a change in pool habitat and substrate composition over time. This information coupled with land-use history should give us an indication of how the stream channel has degraded or recovered in concert with land management activities.

Preliminary results indicate that there has been a small increase in the number of large resting pools available in the main stem of Taneum Creek (Table 2.). In 1936, there were 2.0 large pools per mile of stream and in 1990 there were 2.9 large pools per mile. The percent change, 30%, seems significant, but it is important to realize that 2.9 pools per mile is an extremely small amount of resting pool area in a stream and is not sufficient habitat.

It would appear that the disturbance to the system was prior to the historic survey or that Taneum Creek may never have had large amounts of pool area. There is very little large woody debris or other roughness elements in the lower part of the system and the channel is fairly stable and incised; therefore the amount and recruitment of wood is low. Even though the large pool area is low, other pool data show that there are a fair number of smaller pools, primarily in the upper end of the drainage.

TABLE 2.

CHANGE IN LARGE RESTING POOLS

(>1m DEPTH, >25m2 AREA)

! 936 POOLS/MILE	1990 POOLS/MILE	% CHANGE
2.0	2.9	30

Substrate Distribution

Substrate Distribution was analyzed on a reach by reach basis. The most significant change is seen in the increase of mud and sand in the last two reaches (Figure 1.). Also, the corresponding decrease of spawning size gravels in those two reaches (Figure 2.). Most likely the gravels are being buried by the fine sediments. Another significant point is the sharp decrease in mud and sand and increase in large rubble in Reach #1 (Figure 3.). It is possible that due to the incised nature of the channel and lack of roughness elements that the stream's capacity to transport sediment has increased and is scouting out most of the fine sediments previously deposited in that reach.

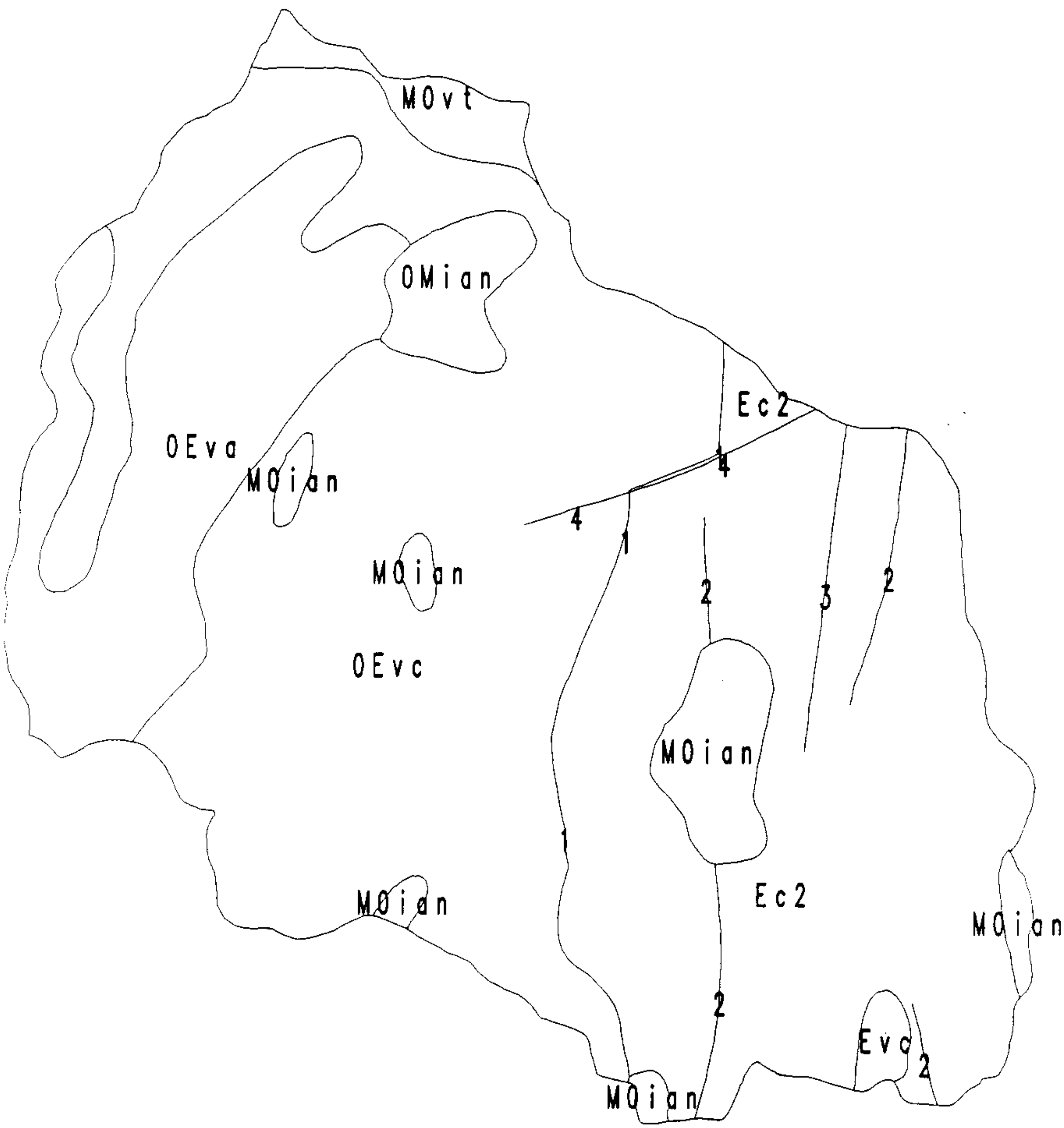
Work to be Completed

Changes in habitat documented through the historic and recent stream surveys will be compared to watershed condition changes derived from the aerial photo and GIS analysis.

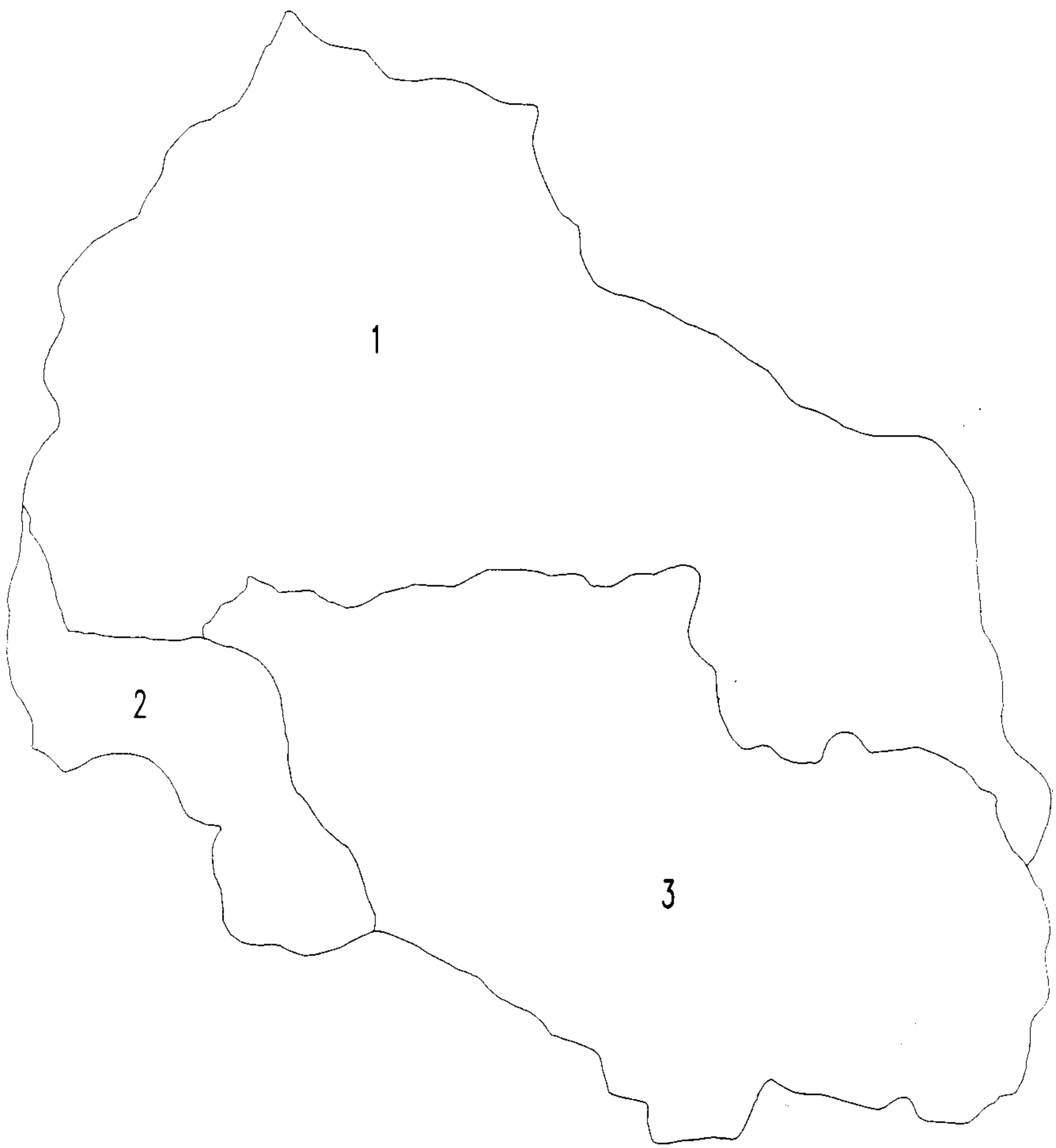
COMPLETED MASHEL RIVER GIS DATA LAYERS

MASHEL RIVER

GEOLOGY COVERAGE

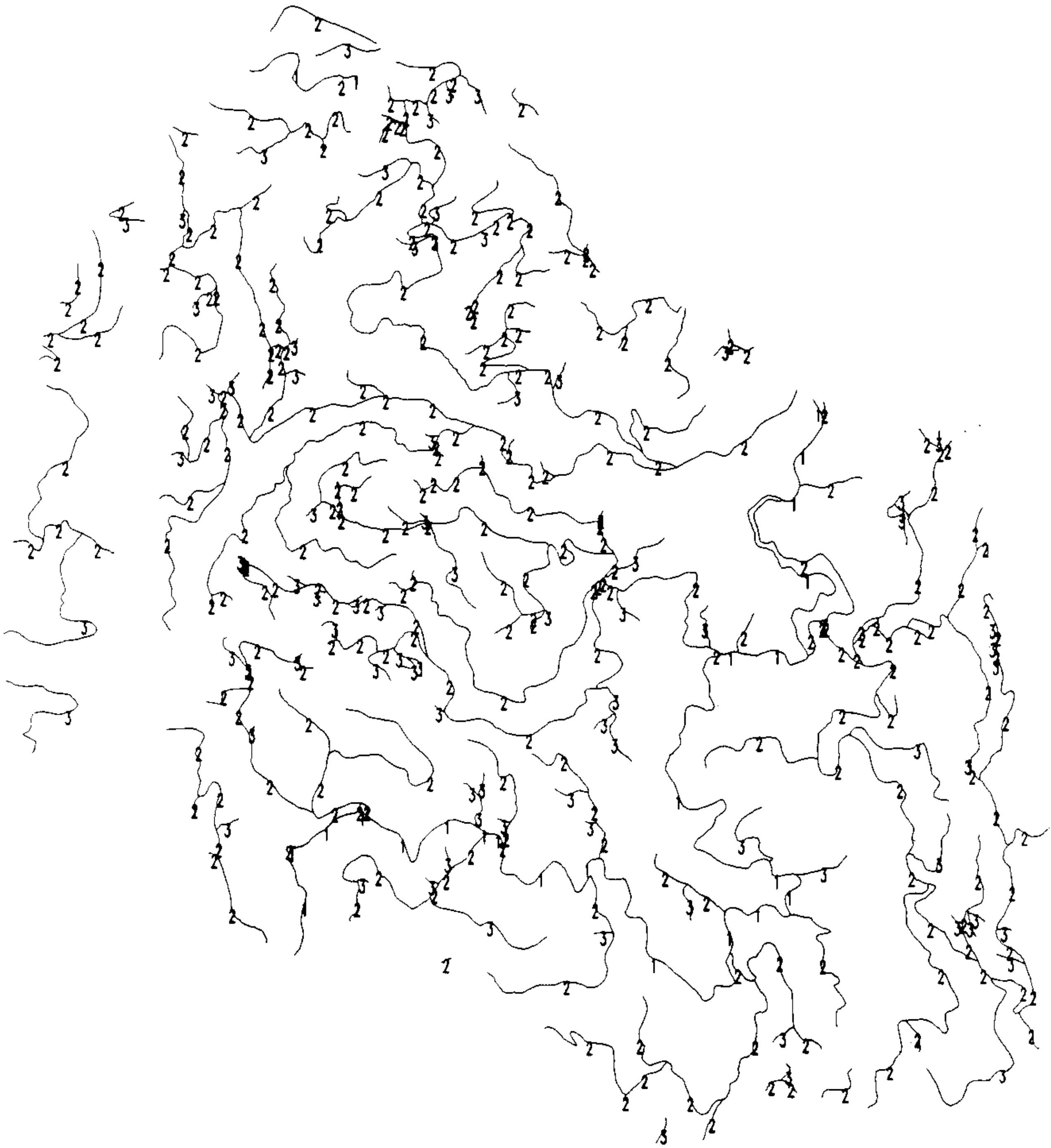


MASHEL RIVER
SUBWATERSHED BOUNDRIES



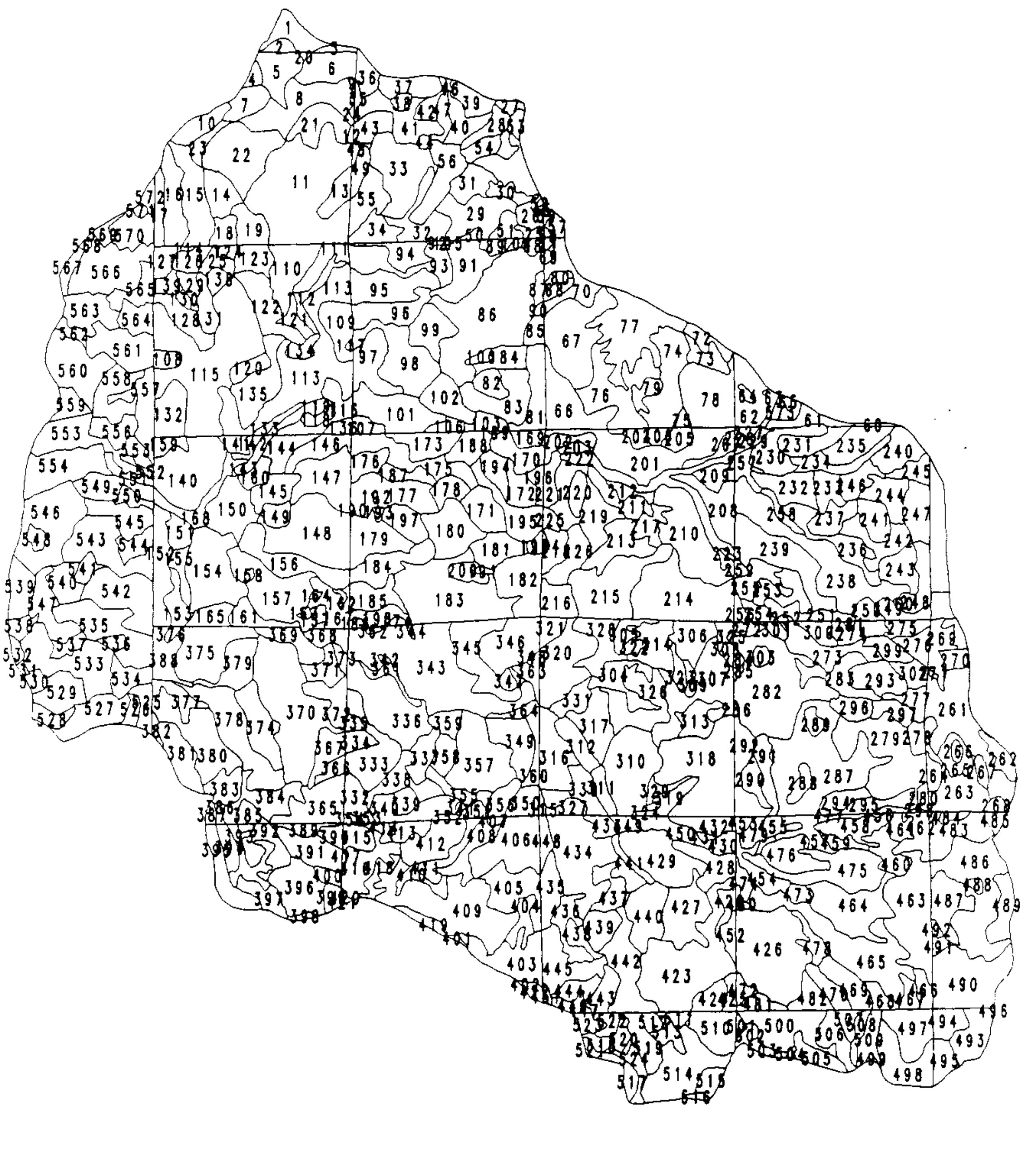
MASHEL RIVER

ROADS COVERAGE



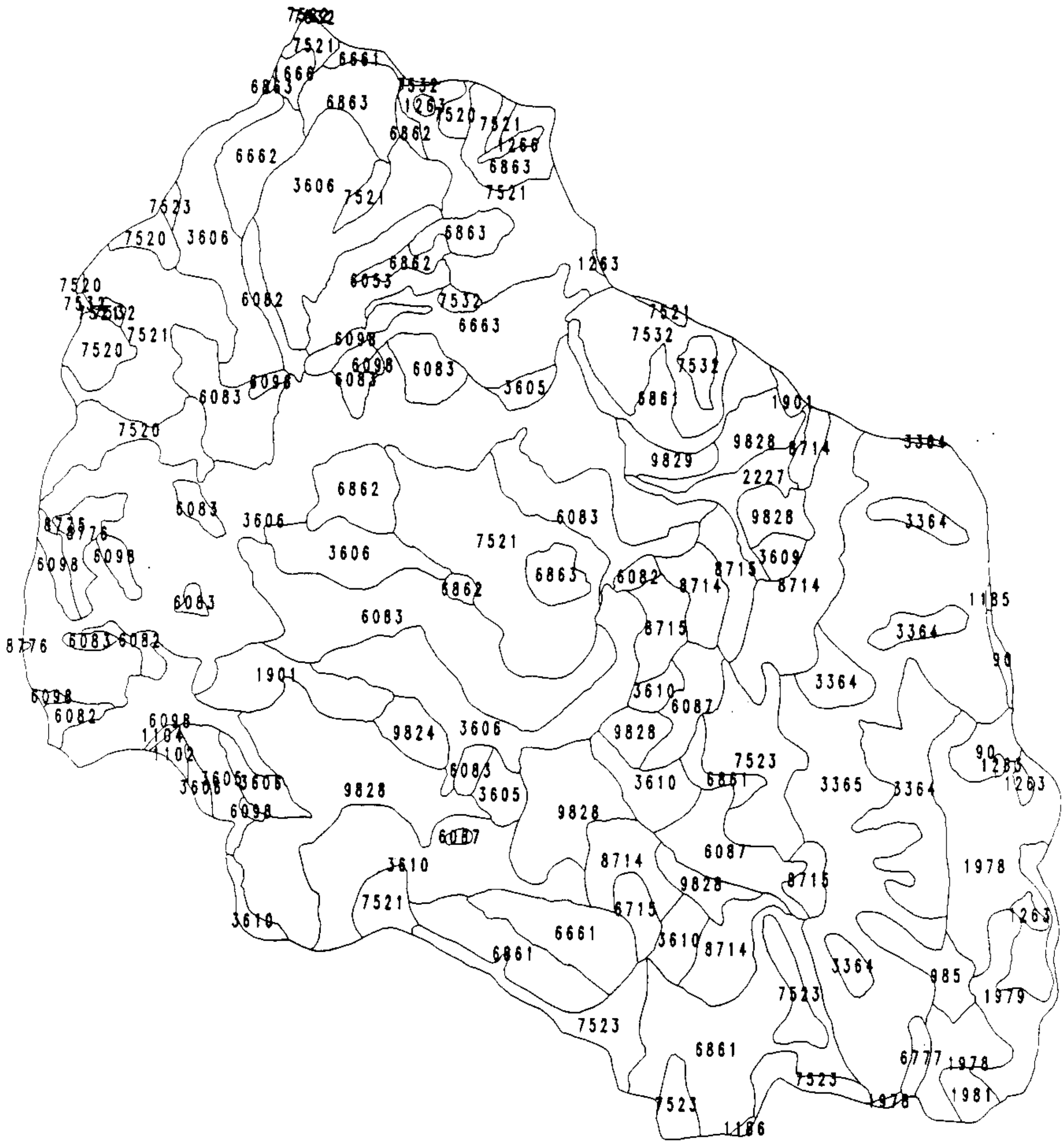
MASHEL RIVER

VEGETATION COVERAGE



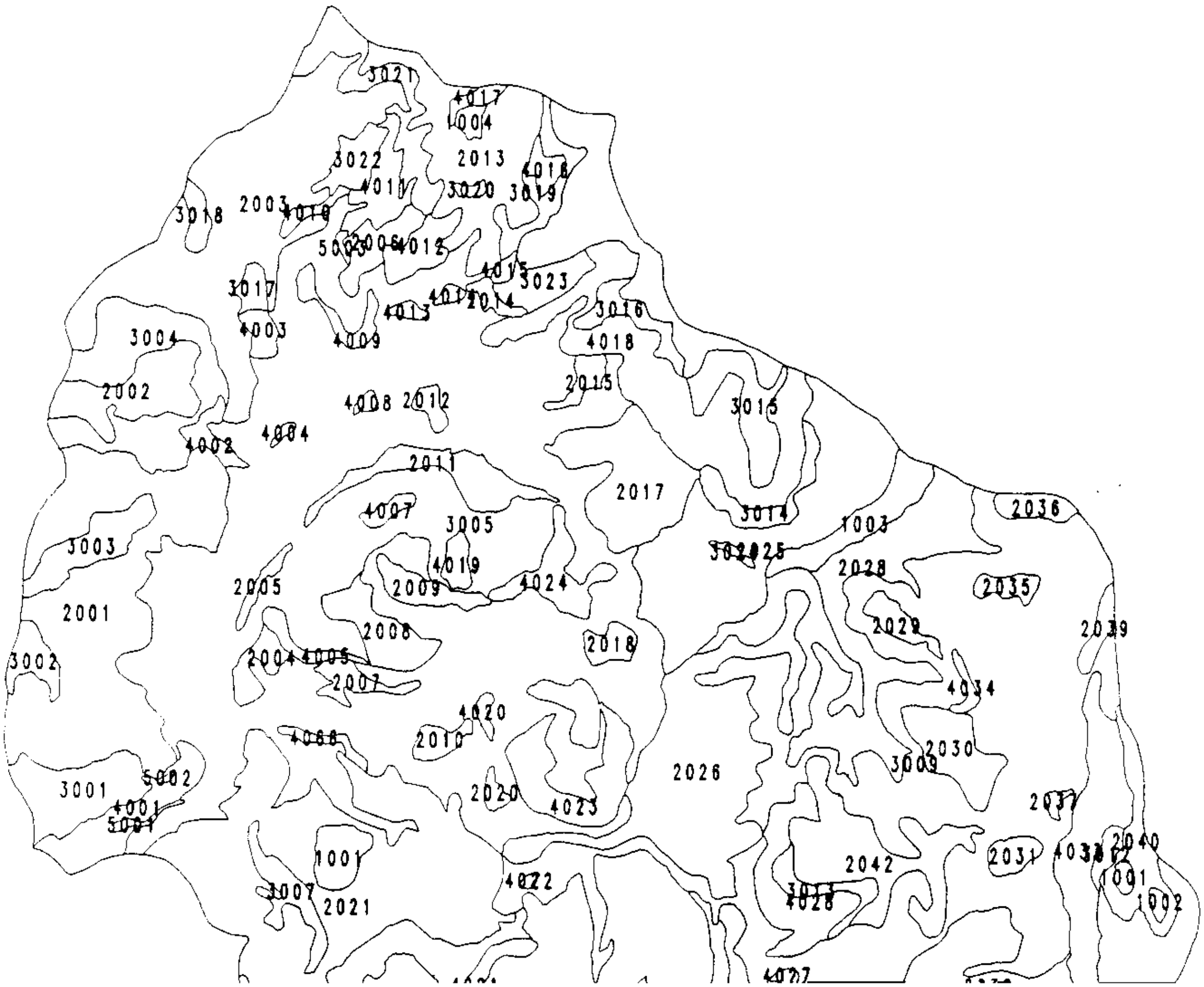
MASHEL RIVER

SOIL S COVERAGE

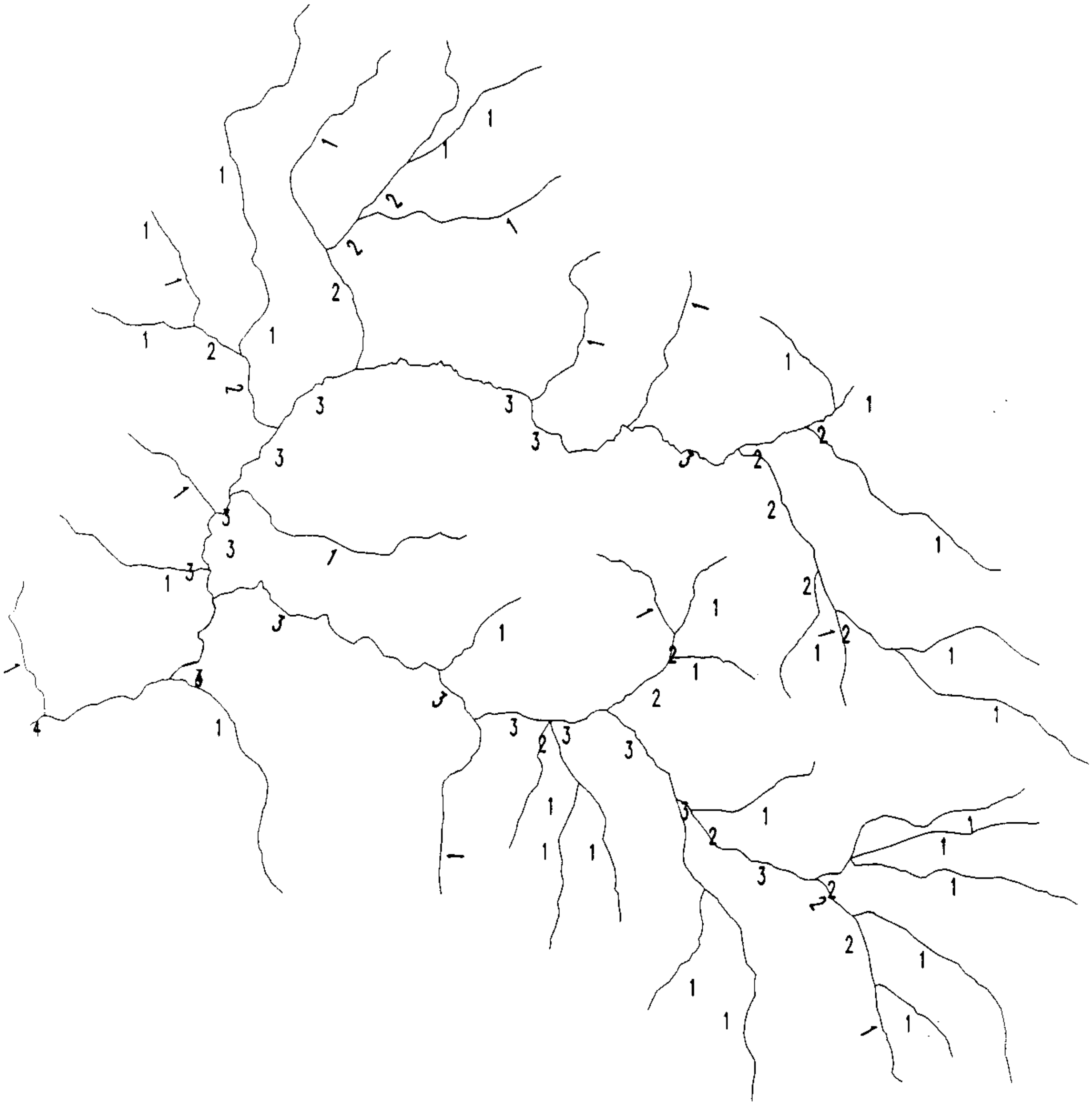


MASHEL RIVER

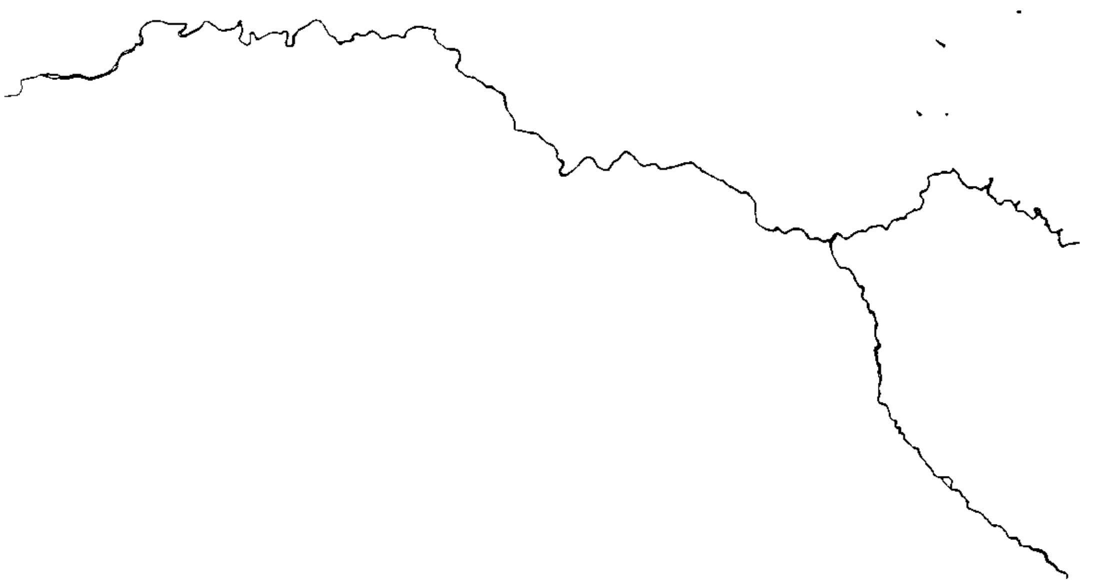
SLOPE COVERAGE



MASCHEL RIVER
STREAM ORDER COVERAGE

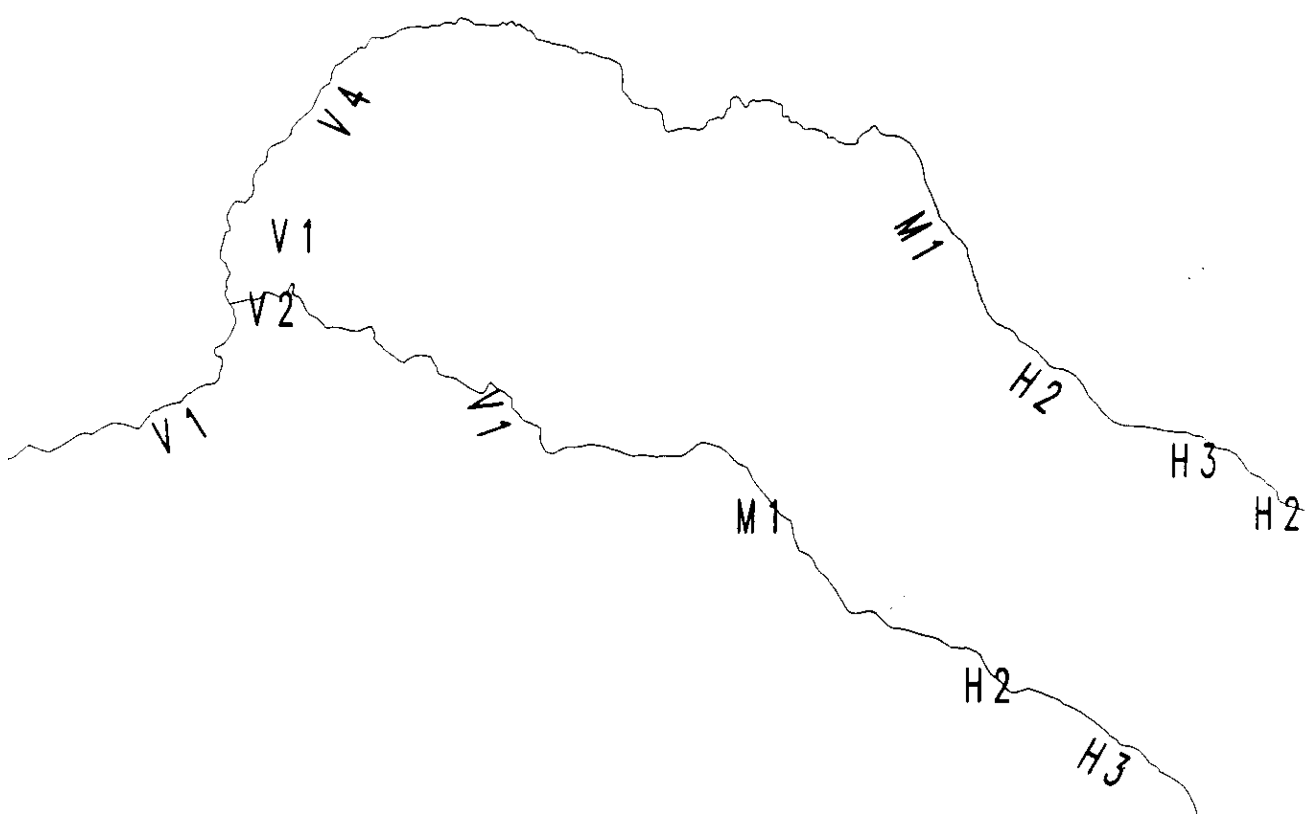


R PARIAN CANOPY OPENING



MASHEL RIVER

VALLEY SEGMENTS



REFERENCES

Abugov, Robert. 1982. Species Diversity and Phasing of Disturbance. Ecology 63(2), pp. 289-293.

Anon. 1975. Photointerpretation Guide for Forest Resource Inventories. U.S. Department of Commerce, National Technical Information Service, Document N76-78636.

Anon. 1990. Riparian Management Guide, Willamette National Forest. U.S. Department of Agriculture, Forest Service, Pacific Northwest Region.

Ashley, M.D., D. Corcoran, and L. Morin. 1978. Vegetation Condition Estimates Using Color Infrared Aerial Photography. In: Integrated Inventories of Renewable Natural Resources: Proceedings of the Workshop. January 8-12, 1978, Tucson, Arizona. USDA Forest Service General Technical Report RM-55, Rocky Mountain Forest and Range Experiment Station, Fort Collins Colorado.

Bailey, Robert G. 1986. Suggested Hierarchy of Criteria for Multi-scale Ecosystem Mapping. Landscape Urban Planning 14: 313-319.

Berg, Dean Rae. 1990. Active Management of Streamside Forests. Masters Thesis, University of Washington College of Forest Resources. 100 pp.

Berris, S.N. and R.D. Harr. 1987. Comparative Snow Accumulations and Melt During Rainfall in Forested and Clear-cut Plots in the Western Cascades of Oregon. Water Resour. Res. 23(1): 135-142.

Bovee, Ken D.. 1978. Probability-of-Use Criteria for the Family Saimonidae. Instream Flow Information Paper No. 4. FWS/OBS-78/07, USDI Fish and Wildlife Service, Cooperative Instream Flow Services Group, Fort Collins, CO. 80 pp..

Bryant, M.D., P.E. Porter, and S.J. Paustin. 1991. Evaluation of a Stream Channel-Type System for Southeast Alaska. Gen. Tech. Rep. PNW-GTR-267. Portland, OR. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 20 pp.

Burns, Robert. 1985. The Shape and Form of Puget Sound. University of Washington Press, Seattle. 100 pp.

Connors, K.F., and Thomas W. Gardner. 1987. Classification of Geomorphic Features and Landscape Stability in Northwestern New Mexico Using Simulated Spot Imagery. Remote Sensing of Environment 22: 187-207. Benda, Lee E.. 1984. Behavior and Effect of Debris Flows on Streams in the Oregon Coast Range. In: Symposium "Delineation of Landslide, Flash Flood and Debris Flow Hazards in Utah", June 14-15, 1984, Utah State University, Logan, Utah.

Culpin, Paul. 1978. Remote Sensing Streams. In: Integrated Inventories of Renewable Natural Resources: Proceedings of the Workshop. January 8-12, 1978, Tuscon, Arizona. USDA Forest Service General Technical Report RM-55, Rocky ' Mountain Forest and Range Experiment Station, Fort Collins Colorado.

Culpin, Paul. 1985. Riparian Area Inventory and Monitoring Using Large Scale Color Infrared Photography. Proc. of the North American Riparian Conference, Tucson, Arizona, April 16-18, 1985. USDA Forest Service General Technical Report RM-120, Rocky Mountain Forest Range and Experiment Station, Fort Collins, Colorado.

Culpin, P., and F. Baston. 1985. Stream/Riparian Area Inventory and Monitoring Using Large Scale Color Infrared Airphotos. Proc. Pecora 10, Remote Sensing In Forest and Range Resource Management,August 20-22, 1985, Colorado State University, Ft. Collins, CO,.

Culpin, P., et al. 1985. A Comparison of Riparian Area Ground Data with Large Scale Airphoto Interpretation. Proc. of the North American Riparian Conference, Tucson, Arizona, April 16-18, 1985. USDA Forest Service General Technical Re Qrt RM-120, Rocky Mountain Forest Range and Experiment Station, Fort Collins, Colorado.

Elassal, A.A. and V.M. Caruso. 1983. USGS Digital Cartographic Data Standards, Digital Elevation Models. Geological Survey Circular 895-B. U.S. Department of the Interior, Geological Survey, Reston, VA. 40 pp.

Everitt, J.H., et al. 1986. Assessment of Grassland Phytomass with Airborne Video Imagery. Remote Sensing of Environment 20:299-306.

Everitt, J.H., D.E. Escobar. M.A. Alaniz, and M.R. Davis. 1987. Using Airborne Middle-Infrared Video Imagery for Distinguishing Plant Species and Soil Conditions. Remote Sensing of Environment 22: 423-428.

Everitt, J. H., D. E. Escobar, M. A. Alaniz, and M.R. Davis. 1989. Using Multispectral Video Imagery for Detecting Soil Surface Conditions. Photogrammetric Engineering and Remote Sensing 55 (4): 46 7-471.

Everitt, J.H., and P.R. Nixon. 1985. False Color Video Imagery: A Potential Remote Sensing Tool for Range Management. Photogram. Eng. and Remote Sensing 51 (6): 675-679.

Everitt, J.H. , et al. 1986. Assessment of Grassland Phytomass with Airborne Video Imagery. Remote Sensing of Environment 20: 299-306.

Fausch, Kurt D., C.L. Clifford, and G. Mit. 1988. Models that Predict Standing Crop of Stream Fish from Habitat Variables: 1950-85. Gen. Tech. Rep. PNW-GTR-213. Portland, OR. U.S. Department of Agriculuture, Forest Service, Pacific Northwest Research Station. 52 pp.

Fonda, R.W.. 1974. Forest Succession in Relation to River Terrace Development in Olympic National Park, Washington. Ecology -55: pp. 927-942.

Frissel, C.A., W.J. Liss, C.E. Warren, and M.D. Hurley. 1986. A Hierarchical Framework for Stream Habitat Classification: Viewing Streams in a Watershed Context. Environmental Management 10(2): 199-214·

Gerten, D.M., and M.V. Wiese. 1987. Microcomputer Assisted Video Image Analysis of Lodging in Winter Wheat· = Photogramm. Eng. and Remote Sens. 53 (1):83-88.

Grant, Gordon. 1988. The RAPID Technique: A New Method for Evaluating Downstream Effects of Forest Practices on Riparian Zones. USFS General Technical Report PNW-GTR-220. Portland, OR.

Greentree, W.J., and R. C. Aldrich. 1976. Evaluating Stream Trout Habitat on Large-Scale Aerial Color Photographs. USDA Forest Service Research Paper PSW-123, Pacific Southwest Forest and Range Exp. Stn., Berkeley, California. 21 pp.

Gross, Michael f., and Vytautas Klemas. 1986. The Use of Airborne Imaging Spectrometer (AIS) Data to Differentiate Marsh Vegetation. Remote Sensing Of Environment 19: 97-103.

Hame, T., and M. Rantasua. 1988. Shuttered Camera-Aerial Color Video Imaging in the visible and Near Infrared. Photogrammetric Engineering and Remote Sensing 54(12):1735-1738.

Hatten, Jim. 1991. The Effects of Debris Torrents on Spawning Gravel Quality in Tributary Basins and Side-channels of the Hoh River, Washington. Hoh Indian Tribe, Forks, WA. I9 pp.

Heede, Burchard H. 1985. Interactions Between Streamside Vegetation and Stream Dynamics. In: Riparian Ecosystems and Their Management: Reconciling

Conflicting Uses, USDA Forest Service, General Technical Report RM 120. pp. 54-58.

Heede, Burchard H.. 1980. Stream Dynamics: An Overview for Land Managers. USDA Forest Service General Technical Report RM-72. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.

Heede, Burchard H.. 1991. Response of a Stream in Disequilibrium to Timber Harvest. Environmental Management vol. 15, No. 2. pp. 251-255.

Hegg, Karl M.. 1978. An Evaluation of Small-Scale Color Infrared Photography for Integrated Resource Inventories.

Howard, John A.. 1970. Aerial Photo~Ecology. Faber and Faber, London. 311 pp.

Janza, Frank J., ed. 1975. Manual of Remote Sensing. American Society of Photogrammetry, Falls Church, Virginia.

Jorgenson, S.E.. 1990. Ecosystem Theory, Ecological Buffer Capacity, Uncertainty and Complexity. Ecological Modelling52(1990) 125-133.

Kovalchik, B. L. and L.A. Chitwood. 1990. Use of Geomorphology in the Classification of Riparian Plant Associations in Mountainous Landscapes of Central Oregon, U.S.A.. Forest Ecology and Management, 33/34. pp. 405-418.

Likens, G.E. and R.E. Bilby. 1982. Development, Maintainance, and the Role of Organic Debris Dams in New England Streams. U.S. Forest Service Research Paper PNW-141, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon. pp. 122-128.

Linsley, R.K., M.A. Kohler, and J.L. Paulhus. 1982. Hydrology for Engineers. McGraw-Hill Book Company. 508 pp.

Lund, H. G., V. J. LaBau, P. F. Ffolliot, and D. Robinson, technical coordinators. 1978. Integrated Inventories of Renewable Natural Resources: Proceedings of the Workshop. Jan 8-12, 1978, Tuscon, Arizona. USDA Forest Service General, Technical Report RM-55, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.

McMahon, Thomas E.. 1983. Habitat Suitability Index Models: Coho Salmon. *FWS/OBS-82/lO.49.* USDI Fish and Wildlife Service, Habitat Evaluation Procedures Group, Ft. Collins, CO. 29 pp..

Meisner, D. 1985. Color Infrared Aerial Video:Publications in Natural Resource Management. Proc. Pecora 10, Remote Sensing In Forest and Range Resource Management, Colorado State University, Ft. Collins, CO, August 20-22, 1985.

Meisner, D. E., and 0. M. Lindstrom. 1985. Design and Operation of a Color Infrared Aerial Video System. Photogramm. Eng. and Remote Sens. 51(5):555-560.

Meisner, D. E. 1986. Fundamentals of Airborne Video Remote Sensing. Remote Sensing of Environment, 19: 63-79.

Meyers, J.W., and Eleanor Emleen Myers. 1985. An Aerial Atlas of Ancient Crete. Archaeology 38 (5): 18-25.

Murphy, M. L., J. M. Lorenz, J. Heifetz, J. F. Thedinga, K. V. Koski, and S. W. Johnson. 1987. The Relationship Between Stream Classification, Fish, and Habitat in Southeast Alaska. U.S.D.A. Forest Service Wildlife and Fisheries Habitat Management Notes R10-MB-10, Tongass National Forest.

Naiman, R.J., H. Decamps, J. Pastor, and C.A. Johnston. 1988. The Potential Importance of Boundaries to Fluvial Systems. Journal of the North American Benthological Society, 7(4):289-306.

Nawa, R. K., C.A. Frissel, and W.J. Liss. 1988. Life History and Persistence of Anadromous Fish Stocks in Relation to Stream Habitats and Watershed Classification. Annual Progress Report Prepared for Oregon Department of Fish and Wildlife, Portland, Oregon.

Orsbom, John F.. 1990. Quantitative Modeling of the Relationships Among Basin, Channel, and Habitat Characteristics for Classification and Impact Assessment. Prepared for the T/F/W Ambient Monitoring Technical Steering Committee, Washington State.

Pickett, S.T.A., and P.S. White. 1985. The Ecology of Natural Disturbance and Patch Dynamics. Academic Press. 472 pp.

Platts, W.S., K.A. Gebhart, and W.L. Jackson. 1985. The Effects of Large Storm Events on Basin-Range Riparian Stream Habitats. Paper presented at the North American Riparian Conference, Tucson, Arizona, April 16-18, 1985. pp. 30-34.

Platts, W.S., W.F. Megahan, and G.W. Minshall. 1983. Methods for Evaluating Stream, Riparian, and Biotic Conditions. USDA Forest Service General Technical Report INT-138, Intermountain Forest and Range Experiment Station, Ogden, Utah, 84401.

Platts; W.S.. 1974. Geomorphic and Aquatic Conditions Influencing Salmonids and Stream Classification with Application to Ecosystem Classification. U.S.D.A. Forest Service.

Remote Sensing Instititute. 1982. Handbook of Remote Sensing in Fish and Wildlife Management. South Dakota State University, Brookings, South Dakota, 57007.

Reutebuch, S.E. and R.D. Rhea. 1988. A Method to Control Large-Scale Aerial Photographs When Surveyed Ground Control is Unavailable. In: Remote Sensing for Resource Inventory, Planning, and Monitoring; Proceedings of the Second Forest Remote Sensing Applications Conference. American Society for Photogrammetry and Remote Sensing, Falls Church, VA. pp. 231-236.

Richards, Keith. 1982. Rivers, Form and Process in Alluvial Channels. Mehtuen & Co. Ltd. London. 361 pp.

Sedell, James R. and Fred. H. Everest. 1991. Historic Changes in Pool Habitat for Columbia Basin Salmon Under Study for TES Listing.

Sedell, J.R., G.H. Reeves, F.R. Hauer, J.A. Stanford, and C. P. Hawkins. 1990. Role of Refugia in Recovery from Disturbances: Modem Fragmented and Disconnected River Systems. Environmental Management, Vol 14, No. 5, pp. 711-724.

Sidle, R.C., Pearce, A.J., and O'Loughlin, C. L.. 1985. Hillslope Stability and Land Use. Watershed Resources Monograph 11, American Geophysical Union, Washington D.C.. 140 pp.

Strahler, A.H., C.E. Woodcock, and J. Smith. 1986. On the Nature of Models in Remote Sensing. Remote Sensing of Environment 20: 121-139.

Swanson, F.J., R.L. Fredriksen, and F.M. McCorison. 1982. Material Transfer in a Western Oregon Forested Watershed. Chapter 8 in: Analysis of Coniferous Forest Ecosystems in the Western United States (R.L. Edmonds, ed.), US/IBP Synth. Ser. No. 14, Dowden, Hutchinson & Ross, Inc., Stroudsburg, Pennsylvania.

Swanson, F. J., T. K. Kratz, N. Caine, and R. G. Woodmansee. 1988. Landform Effects on Ecosystem Patterns and Processes. Bioscience 38 (2) :92-98.

Tabor, Rowland W.. 1987. Geology of Olympic National Park. Pacific Northwest National Parks & Forests Association, 83 S. King Street, Seattle, WA. 144 pp.

Thomson, K.B., R.K. Lane, and S. C. Csallany, eds. 1973. Remote Sensing and Water Resources Management. American Water Resources Association, Urbana, Illinois.

Toews, D.A.A and M.J. Brownlee. 1981. A Handbook for Fish Habitat Protection on Forest Lands in British Columbia. Land Use Unit, Habitat Protection Division, Field Services Branch, Department of Fisheries and Oceans. Vancouver, B.C. 165 pp.

Treadwell, B. D., P. L. Warren, and S. Berwick. 1985. Emerging Technologies for the Assessment and Monitoring of Wildlife Habitat in Developing Countries. Proc. Pecora 10, Remote Sensing In Forest and Range Resource Management, August 20-22, 1985, Colorado State University, Ft. Collins, CO.

Treadwell, B. D., P. L. Warren, and S. Berwick. 1985. Emerging Technologies for the Assessment and Monitoring of Wildlife Habitat in Developing Countries. Proc. Pecora 10, Remote Sensing In Forest and Range Resource Management, August 20-22, 1985, Colorado State University, Ft. Collins, CO.

Trotter, Eleonora H.. 1990. Woody Debris, Forest-Stream Succession, and Catchment Geomorphology. J. N. Am. Benthol. Soc., 9(2), pp. 141-156.

Turner, M. G. and R.H. Gardner, eds. 1991. Quantitative Methods in Landscape Ecology: An Introduction. Springer-Verlag, N.Y. (In Press).

Vlachos, Evan. 1985. Assessing Long-Range Cumulative Impacts. In: Environmental Impact Assessment, Technology Assessment, and Risk Analysis. Edited by V.T. Covello et al. NATO ASI Series, Vol. G4. Springer Verlag, Berlin. pp 50-80.

Ward, J.V.. 1989. The Four-Dimensional Nature of Lotic Ecosystems. J. N. Am. Benthol. Soc., 8(1), pp. 2-8.

Waxing, R.H. and W.H. Schlesinger. 1985. Forest Ecosystems: Concepts and Management. Academic Press, Inc.. 339 pp.

Warner, William S.. 1990. A PC-based Analytical Stereoplotter for Wetland Inventories; An Efficient and Economical Photogrammetric Instrument for Field Offices. Forest Ecology and Management, 33/34, pp. 571-581.

Warner, William S.. 1988.

Washington Department of Ecology. 1985. Forest Riparian Habitat Study Phase I Report. WDOE 85-3, April, 1985.

Washington Department of Wildlife. 1988. Field Procedures Handbook: Characterization of Riparian Management Zones and Upland Management Areas with Respect to Wildlife Habitat.

Whittier, T.R., D.P. Larson/R.M. Hughes, C.M. Rohm, A.L. Gallant, and J.M. Omernick. 1987. The Ohio Regionalization Project: A Compendium of Results. U.S. Environmental Protection Agency EPA@/600/3-87/025.

Woodcock, C.E., and Alan H. Strahler. 1987. The Factor of Scale in Remote Sensing. Remote Sensing of Environment 21:311-332.

Woolridge, David D.. 1978. The Benchmark Research Watersheds. College of Forest Resources, University of Washington, Seattle, WA. 23 pp.

Yoshinori, T. and K. Osamu. 1984. Vegetative Influences on Debris Occurrences on Steep Slopes in Japan. Presented at the Symposium on Effect of Forest Land Use on Erosion and Slope Stability in Honolulu, Hawaii, USA, May 1984.